*Annual Subscription Price, $4.* 126 *Published Ten Times a Year.*

# Astronomy AND Astro-Physics

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## JUNE, 1894.

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OFFICE OF PUBLICATION:

CARLETON COLLEGE, NORTHFIELD, MINN.

**Wm. Wesley & Son, 28 Essex St. Strand, London, are foreign agents.**

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PLATE XIII.

GALE'S COMET, 1894, MAY 3.

$8^h\ 20^m$ to $10^h\ 35^m$ STANDARD PACIFIC TIME.

6-inch Portrait Lens, E. E. Barnard, Lick Observatory.

ASTRONOMY AND ASTRO-PHYSICS No. 126.

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# Astronomy and Astro-Physics.

VOL. XIII, No. 6. JUNE, 1894. WHOLE No. 126.

## General Astronomy.

### PHOTOGRAPHS OF GALE'S COMET.*

E. E. BARNARD.

This comet was discovered by Gale at Sydney, New South Wales, April 2.944 G. M. T. in

$$\alpha = 2^h\ 30^m\ 48^s;\ \delta = -55^\circ\ 38'$$

A very rapid northeasterly motion brought it above our southern horizon in the latter half of April.

Unfavorable weather prevented its being seen here until Saturday night, April 28.

As this was a public night and the Observatory was crowded with visitors, no careful observation could be made of it. However, I got permission from the visitors to turn the 12-inch for a moment to its place and found the comet at once. It was large, round and condensed with no trace of tail to the hasty glance I necessarily gave to it. Looking along the tube, I saw the comet was easily visible to the naked eye as a hazy star of the 5th magnitude.

A quick pointing on it—afterwards corrected by a pointing on a star, in nearly the same position above the horizon, gave the following place at $7^h\ 51^m$ Mt. Hamilton mean time:

$$\alpha = 7^h\ 18^m.7$$
$$\delta = -26^\circ\ 19'$$

The comet was certainly not a promising object for photography. On the night of April 29th, however, I gave an exposure of one hour upon it with the 6-inch Willard portrait lens, and the comet was shown to have a very slender thread-like tail over a degree long. On this date no trace of a tail could be seen in the 12-inch. No opportunity occurred to get another satisfactory photograph until May 2d when an exposure of one hour and fifteen minutes showed the tail distinctly for about four degrees. The sky was hazy.

On May 3d another photograph was secured with two hours

* Communicated by the author.

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and fifteen minutes exposure upon which the tail was easily traceable eight or ten degrees. The sky was thick on this date also. In this case there was a tendency in the tail to split up into several strands.

On May 4 another photograph made through haze with two hours and five minutes exposure was very satisfactory though the condition of the sky almost forbade any attempt at photography.

Considerable changes had taken place in the appearance of the tail between the 3rd and the 4th, especially near the head. In the pictures previous to the 4th the slender tail retains its brightness up to its junction with the head. On the 4th however, the main tail is as long and slender as on the 3rd, but singularly enough it tapers down to a point and vanishes nearly one degree before reaching the head! There are however, two short tails nearly a degree long and at an angle of about 15° to each other that spring out from the head on each side of where the main tail should join. The northern one of these just narrowly misses a junction with the long tail, but passes free to the north of it. A good deal of diffused cometary matter appears between these two tails.

A fine photograph was obtained on May 5th* with two hours and thirty minutes exposure. This gives a rather complicated tail fully ten degrees long.

The tail leaves the head as a thin streak; at one degree distant it begins gradually to widen out, and a faint streamer runs close parallel with it to the north. At some 3° from the head a division occurs in the tail the south component being a very slender thread, while the northern component broadens and its northern edge is distinctly convex. While the southern side of the slender, thread-like tail near the head is well defined and free from minor tails or diffusion, the northern side has a faint and diffused brushing out from the head at a considerable angle to the direction of the tail itself.

Another photograph on the 8th with two hours and thirty minutes exposure partly in moonlight shows only the feeblest traces of tail. Though this can feebly be traced for upwards of 4° it is difficult to make much out of it. There seems to be several strands from the head, a very thin one of which divides ½° from the head and forms two faint strand-like tails running out for three or four degrees.

The peculiar characteristic of this comet is its slender tail and

* The glass positive was so badly broken in transit that it could not be reproduced.—*Ed.*

round head. There was no apparent development of the head as in comets usually possessed of a tail—that is, there was no apparent diffusion of the material of the head to form the tail.

I have forwarded two of these photographs for illustration and if they are successfully reproduced, I think it will be seen that photographically this is a very important and interesting comet.

To those not familiar with the subject, I would say that, as the comet was moving rapidly among the stars, the telescope was made to move accurately with it to keep the image stationary on the plate, this threw the motion on to the stars which are drawn out into lines of light, in length corresponding to the motion of the comet.

MT. HAMILTON, 1894, May 12.

---

## THE FORMS OF THE DISCS OF JUPITER'S SATELLITES.*

WILLIAM H. PICKERING.

In his interesting paper in the April number of ASTRONOMY AND ASTRO-PHYSICS, Professor Barnard criticises my statement that the first satellite of Jupiter, even when not in transit, usually presents an elliptical disc. While I confess myself very much surprised that a phenomenon which appeared to us so obvious in Arequipa has not been confirmed by the 36-inch telescope, I can only say that the phenomenon there was very obvious, and was seen and correctly described by several persons who were entirely unfamiliar with the use of a telescope. That is to say, they would state correctly which one of the satellites was elongated and would describe correctly in words the direction in which the elongation took place. Upon six nights measures of the position angle of the elongation were secured by both Mr. Douglass and myself. Each measure is the mean of six readings, taken alternately in opposite directions. These angles have not as yet been corrected for the constants of the instrument, but a comparison of the uncorrected angles will serve to show the extent of the agreement between the two observers. It will be seen that the position-angle of the elongation of the disc, as measured by Mr. Douglass, uniformly exceeds the value as given by myself by several degrees. As the observations were nearly all made in one portion of the sky, with the observer's head consequently always in the same position, a personal correction of this sort due to a

* Communicated by the author.

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slight astigmatism of the eye, is perhaps not surprising. The mean value of this constant difference amounts to 7°.1. In the following table the first column gives the date of the observation, the second the observed position-angle of the major axis of the disc, the third the average deviation of the six readings which combined give the individual measures, the fourth gives the initials of the observers, the fifth the differences between their results, and the sixth these differences corrected by the constant angle 7°.1.

DISC OF JUPITER'S FIRST SATELLITE.

| Date. | P. A. | Dev. | Obs. | Diff. | Cor. |
|---|---|---|---|---|---|
| | ° | ° | | ° | ° |
| 1892, Nov. 28 | 100.5 | 3.7 | | | |
| " " | 108.3 | 8.7 | P | + 7.8 | + 0.7 |
| Dec. 26 | 100.0 | 7.6 | D | | |
| " " | 106.1 | 4.9 | P | + 6.1 | − 1.0 |
| " 29 | 103.8 | 5.0 | D | | |
| " " | 116.8 | 3.2 | P | + 13.0 | + 5.9 |
| 1893, Jan. 1 | 90.0 | 6.0 | D | | |
| " " | 95.7 | 3.4 | P | + 5.7 | − 1.4 |
| " 13 | 99.2 | 4.2 | D | | |
| " " | 104.8 | 3.7 | P | + 5.6 | − 1.5 |
| " 17 | 92.4 | 3.8 | P | | |
| " " | 97.9 | 3.2 | D | + 4.6 | − 2.5 |
| | | ± 4.8 | | + 7.1 | ± 2.2 |

On account of the high power employed, the planet as a usual thing did not come into the field of view, and it is perhaps needless to add that precautions were taken to guard against all outside causes which might vitiate the accuracy of the observations. Thus, we took pains that the settings should not be in any way biased by the positions of the other satellites, should any of them happen to be in the field at the same time. Our only guide in setting the micrometer was the ellipticity of the disc itself. The mean value of the results given in the last column, 2°.2, indicates the average difference between the corrected measures of the two observers upon any given night. It does not seem to me that we could have set the micrometer as accordantly as this, if the disc of the satellite had appeared to us to be perfectly round. I think we may rule out any possible distortion produced by the telescope, since the discs of the other satellites were not similarly effected.

No matter what may have been the cause, there was some peculiarity about this satellite which was apparent when it was

not in transit, but which vanished at regular intervals of $6^h\ 32^m$. But apparently when not in transit, Professor Barnard sees nothing peculiar about this satellite, and it is this fact which chiefly surprises me. For even if we admitted a bright equatorial belt, as suggested by Professor Barnard in *Monthly Notices* for January, 1894, as the true explanation of the phenomena, that would not explain away the difficulty, that the 13-inch in Arequipa showed easily a peculiarity in the satellite when off the disc of the planet that the 36-inch could not detect. Moreover, the hypothesis of an equatorial belt does not explain why at regularly recurring intervals the disc of the satellite appeared to us to be circular. It must be understood that I do not deny the existence of the equatorial belt described by Professor Barnard, I merely state that such a belt could not have produced the effects observed by us in Arequipa. In this connection it may be stated that the figures published in ASTRONOMY AND ASTRO-PHYSICS for June, 1893, represent the discs of the satellites at maximum ellipticity, and that therefore the observer will usually find them much more nearly circular than they are there represented.

It is interesting to note that upon two occasions the disc of the fourth satellite appeared to Professor Barnard to be elongated in a north and south direction, just as it did to us in Arequipa. It is also satisfactory to note that our observations regarding the shape of the surface detail upon the third satellite, including the polar spot, were confirmed by him at this opposition, as is also true of our observations upon the polar spot of the fourth.

In conclusion, I may add that while I have not thought it worth while, on account of atmospheric conditions, even to attempt to verify my results by observations made in Cambridge, that I expect to devote considerable time to the matter at this next opposition, which I hope to be able to observe under unusually satisfactory conditions in Arizona.

HARVARD COLLEGE OBSERVATORY,
April 12, 1894.

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## A GRAPHICAL METHOD FOR DETERMINING THE APPARENT ORBITS OF BINARY STARS.*

CHARLES P. HOWARD.

The following graphical method for determining the apparent orbits of binary stars, is believed to have some novelty and for

* Communicated by the author.

many stars to possess some advantage over those ordinarily used, but on these points the writer speaks with diffidence, being well aware that as an amateur he is hardly sufficiently familiar with other methods to be qualified to make comparisons between them.

Assuming, that the best orbit to be obtained, is the one which while fulfilling the law of equal areas, brings the calculated and observed positions of the same date into the closest agreement; this method is an attempt to carry out this principle in the most thorough manner possible.

An outline of it has already been given in Gould's *Astronomical Journal* for Feb. 4, 1891, incidentally in working out the orbit of the companion of Sirius, but as the novel feature of the method, *viz.*, the process employed for plotting the position of the companion on the assumed ellipse, for the dates of the observed positions, was there only referred to but not described, it is here given in full, while the other steps are simply stated as concisely as possible.

Proceeding to plot the orbit in the manner described in the article above referred to,

1. Reduce the number of positions to be plotted, by taking the average date, position angle and distance, of the groups of observations that admit of such treatment.

2. .Plot these positions to a suitable scale, say of one inch to the second of arc.

3. Mark each plotted position with its date.

4. Draw among them a trial ellipse to average all as nearly as possible.

5. Mark on the ellipse the position of the companion star at the two dates that an inspection of the observations indicate to be the most trustworthy. Usually the greater the interval between them the better.

Then because the companion conforms to the law of equal areas it follows that if its position on the ellipse is thus fixed for these two dates, it is necessarily fixed for all other dates, including of course the date of each plotted observed position. The problem now, is to find a quick and easy graphical method to plot on the trial ellipse the position of the companion on the date of each plotted observed position.

In nearly all binary stars, the observed position angles and distances are reliable to two or three significant figures only, while it is not difficult with ordinary care and skill to execute a drawing with such accuracy that all measurements taken from it

shall be reliable to three or four significant figures. Hence any artifice that will enable us to quickly locate upon the ellipse to this degree of accuracy, a series of points such that the radius vectors passing through them will divide the ellipse according to the law of equal areas, is one by all means to be taken advantage of. Moreover, no matter how rough or wanting in extreme precision it may at first sight appear to be, its capacity to fulfil the above condition is sufficient justification for its use and is the only criterion by which it should be judged.

The following is a description of the artifice used by the writer in obtaining the orbit above referred to, and while easy and rapid of execution (to locate a series of 30 positions on the trial ellipse for Sirius requiring less than an hour's work), its accuracy amply meets the requirements of the case and is fully equal to the other processes of drawing, the positions so determined being perfectly reliable to three or four significant figures.

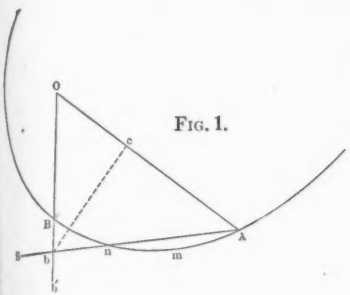


FIG. 1.

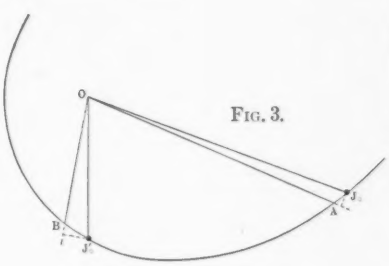


FIG. 3.

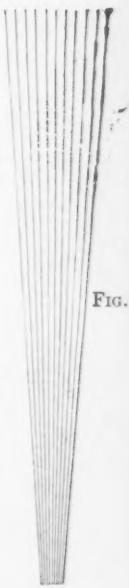

FIG. 5.

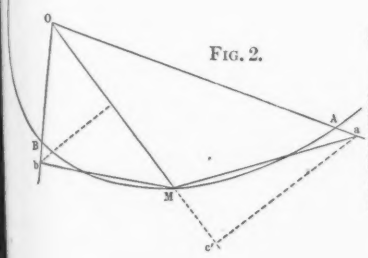


FIG. 2.

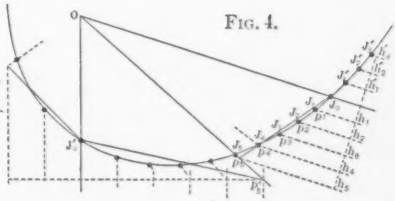


FIG. 4.

In Fig. 1, let *O* be the larger star, *AmnB* the apparent orbit of the companion, as represented by the best trial ellipse that can be drawn among the plotted observed positions; *A* and *B* the two most trustworthy positions of the companion at fixed dates. The area of the elliptic sector *OAmnB*, on the scale of the drawing, is the area described by the apparent radius vector in the

interval of time between the two dates. Now this area is equal to the area of the triangle $OAb$, formed by intersecting the line $OB$, produced by the straight line $As$ drawn so as to make the small internal area $Amn$ equal to the small external area $Bbn$. The equality of these small areas is best adjusted by stretching from $A$ to $S$ a fine black thread and marking the point $b$ on the line $OB$, produced when the areas are equal.

Although these small areas are dissimilar in shape, the error due to visually estimating their equality is remarkably small, partly due to the fact that any change in the direction of the line $AS$ simultaneously increases one area and diminishes the other.

Having thus formed the triangle $OAb$; its area and therefore that of the elliptic sector can be measured on the drawing as equal to $1/2(AO \times bc)$; $bc$ being the altitude, and $OA$ the base, of the triangle.

When the points $A$ and $B$ are so far apart that $b$ cannot be located with sufficient accuracy by the use of one triangle, two triangles can be used as in Fig. 2. These have a common base $OM$, and their combined area will be simply $1/2(bc^* + ac') \times OM$.

When $A$ and $B$ cannot be reached by two triangles, three or more can then be used; to decide this point requires the exercise of judgment, but the use of the check on the accuracy of the plotting to be described below, determines when the triangles have been stretched beyond their limit of accuracy.

By dividing the area of the sector $AOB$ by the interval in years between the dates established for the points $AB$, the area described by the companion in one year is obtained; which yearly area denote by $k$.

We next wish to establish on the trial ellipse the place of the companion for the 1st day of January next preceding the dates fixed for the points $A$ and $B$ so as to be able to locate on the ellipse the position of the companion on the 1st of January for any series of years.

For the point $A$, Fig. 3, let $y_0$ be the fractional part of the date, and $h_0$ be the altitude of the triangle having $OA$ for its base and $y_0k$ for its area; then,

$$h_0 = \frac{2\,y_0 k}{OA}.$$

Hence if a line is drawn parallel to $OA$ at a distance $h_0$ the point where it cuts the ellipse is the required position for January 1st, the curvature of the ellipse being usually insensible for so short an interval of time.

* The letter $c$, omitted by engraver, should be on line $OM$ at foot of perpendicular.—*Ed.*

Repeat the same process for the point $B$ and we have established two positions for the companion on Jannary 1st of two definite years, *viz.*, those corresponding to the dates of $A$ and $B$; call these positions respectively $J_0$ and $J_0'$ in Figs. 3 and 4.

It is now an easy matter to plot the position of the companion on the trial ellipse for January 1st for a series of years.

In fig. 4, starting with $OJ_0$ as a common base, form a series of triangles on both sides of it, such that

| | | | |
|---|---|---|---|
| the area of | the 1st | triangle shall equal | $k$ |
| " | 2d | " | $2k$ |
| " | 3d | " | $3k$ |
| " | 4th | " | $4k$ |
| | &c. | | &c. |

The altitude of the 1st triangle will then be $\frac{2k}{OJ_0} = h$

| | | | |
|---|---|---|---|
| " | 2d | " | $2h$ |
| " | 3d | " | $3h$ |
| " | 4th | " | $4h$ |
| | &c. | | &c. |

On both sides of $OJ_0$ and parallel to it, draw a series of lines, $h_1p_1$, $h_2p_2$, $h_3$, $p_3$, $h_4p_4$, etc. at the distances $h$, $2h$, $3h$, $4h$, etc. These are to be drawn outside of the ellipse, to meet it as shown in the figure. Next lay a straight edge from $O$ to near the point where the first parallel line touches the ellipse, and from $J_0$ stretch a thread to intersect the straight edge on the line $h_1$, $p_1$, swinging them about the points $O$ and $J_0$ respectively, until while this condition is fulfilled, the thread gives equal areas inside and outside the arc; then draw the radius vector represented by the straight edge, and the point where it intersects the curve will be the position of the companion on January 1st, one year from the date of $J_0$.

Repeat this process for each of the parallel lines, on both sides of $OJ_0$ and we obtain as many points of the desired series on the ellipse as we have formed triangles.

Next take $OJ_0'$ as the base of a similar series of triangles formed on both sides of it, and in the same way draw the radius vectors whose intersection with the ellipse locate the position of the companion for January 1st of each year.

Between $J_0$ and $J_0'$ the two series of triangles will overlap, and one or more positions as $J_3$ can be located by both series. This is a valuable feature of this method, because it can be used to check the accuracy of the work of plotting the yearly positions up to this point. With attention to all the niceties of drawing it is surprising how exactly the same position can be located from

two bases, and this fact gives confidence in the reliability of positions so plotted.

The radius vector passing through the extreme positions thus located, can now be taken as new bases from which to start new series of triangles, and so on until the yearly positions are extended all the way around the ellipse and check with the periodic time as derived below.

After the place of the companion on the trial ellipse for January 1st of each year has been thus found, it is an easy matter to plot its place for the exact date of each plotted observed position; the fractional parts of the year being taken off the scale represented in fig. 5, in the usual manner, except that here too, judgment must be used in making an allowance for the continually varying length of the arc described in successive years.

Having thus obtained the series of positions on the trial ellipse corresponding to the dates of each plotted observed position, each observed position is joined to each calculated position of the same date by an arrow. These by their length and direction bring plainly to view the discrepancies between the two series of positions.

If such discrepancies are systematic and extend over several years, and, moreover, if their magnitude is greater than the estimated errors of the plotted observed positions, it is evidence that the trial ellipse is not the most exact that the observations are capable of yielding. The length and trend of the arrows also indicate the character of the modifications which must be made in the first trial ellipse to give a second ellipse that will more accurately represent the observations.

By repeating the above process several times an elliptic orbit will soon be obtained which gives the best average of all the plotted observed positions to be arrived at by this method.

The periodic time of the final ellipse is found as follows; measure on the drawing its major axis $a_1$, and its minor axis $b_1$, then representing the area described in one year by $k_1$, the periodic time is

$$\frac{0.7854 a_1 b_1}{k_1}.$$

## Orbit of Sirius.

### *Possible Evidence of a More Distant and Smaller Companion.*

The orbit of Sirius is particularly well adapted to illustrate the advantages of the graphical method above described, and is therefore the one selected for the purpose. In Figs. 6, 7, 8 and 9, the po-

sitions plotted as small black circles are those given by Professor Burnham on p. 387 of the *Monthly Notices* of the Royal Astronomical Society, for April, 1891, with one exception, *viz.*, for the year 1869 the position 1869.21, 68.9, 11.06 was plotted (this being the average of the last three positions for that year). The points of the arrows rest on the calculated positions of the same dates.

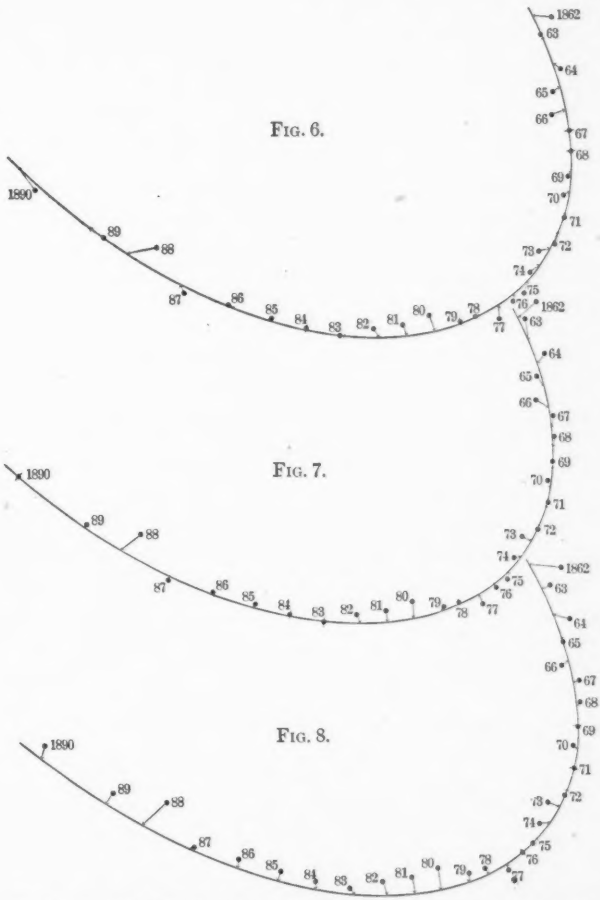


FIG. 6.

FIG. 7.

FIG. 8.

Fig. 6 shows the first trial ellipse adopted as giving the best average of all the plotted positions. This it does very satisfactorily, and if no further test could be applied, would be pronounced good. But when all the observed positions are joined

to all the calculated of the same date, it is at once apparent that it does not represent the observations as well as might be. Some of the arrows are longer than the accuracy of the observations would seem to justify, as for instance '89 and '90, and for many consecutive years ('64 to '78 and again '87 to '90), they point in the same direction. If the assumed positions of the companion on the ellipse for the same dates is advanced or carried back, which can easily be done, it does not help the matter, and evidently this is not the best orbit that the observations will yield. It gives a period of about 53 years.

Fig. 7 shows the second trial ellipse; and is better, the first having been used as a guide. From '83 to '90 the agreement of the two series of positions is remarkable and gives confidence in the accuracy of the plotted observed positions and also gives an indication of how closely the finally accepted orbit should agree with them. But between the years 1862 and 1871 the length, but particularly the direction of the arrows, shows a large systematic discrepancy, that also prevents this ellipse from being accepted as the true orbit. Its period is 55 years.

Fig. 8 shows the best ellipse that the writer could obtain, free from systematic discrepancies, in the direction of the companion's path, by continuing this process five or six times, and yet it can hardly be said to represent the observations better than the others. For here a new systematic discrepancy comes prominently to the front; from '62 to '69 all but one of the observed positions lie outside of the ellipse, while from '78 to '90 all without exception lie well within it. This is the peculiarity that gave the writer so much trouble in 1890 and at that time led him at first to suspect an advance of the periastron, but finally to adopt an elliptic orbit of longer period than usually assigned as the most probable explanation of it. The period of this ellipse is also 55 years.

In all the writer has tried more than 20 different ellipses without obtaining one that was thoroughly satisfactory, having to contend in every case with two persistent characteristic discrepancies, and whenever one of them was reduced the other immediately became prominent.

They were (1st,) in the assumed ellipse the motion was such that too great areas were invariably described between the years '62 and '69, and too small areas between the years '80 and '90; and (2d) all the observed positions between the former dates fell outside of the ellipse, and all those between the latter dates fell inside.

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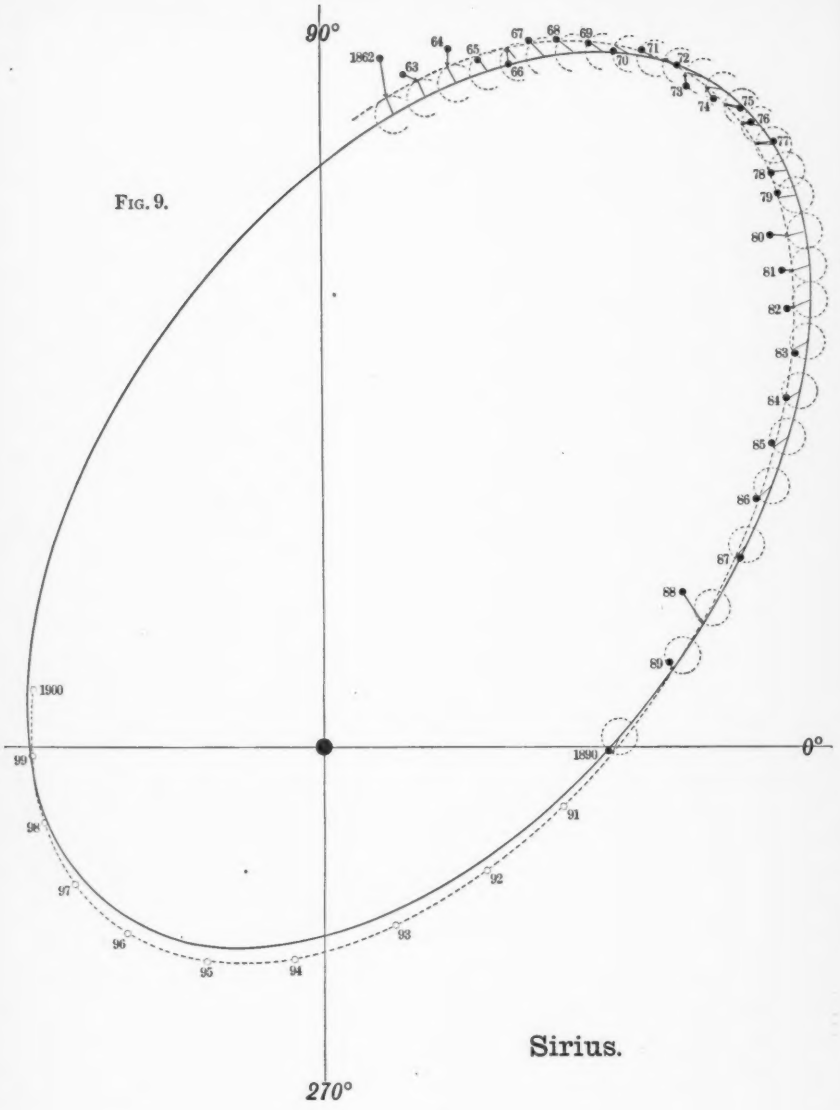
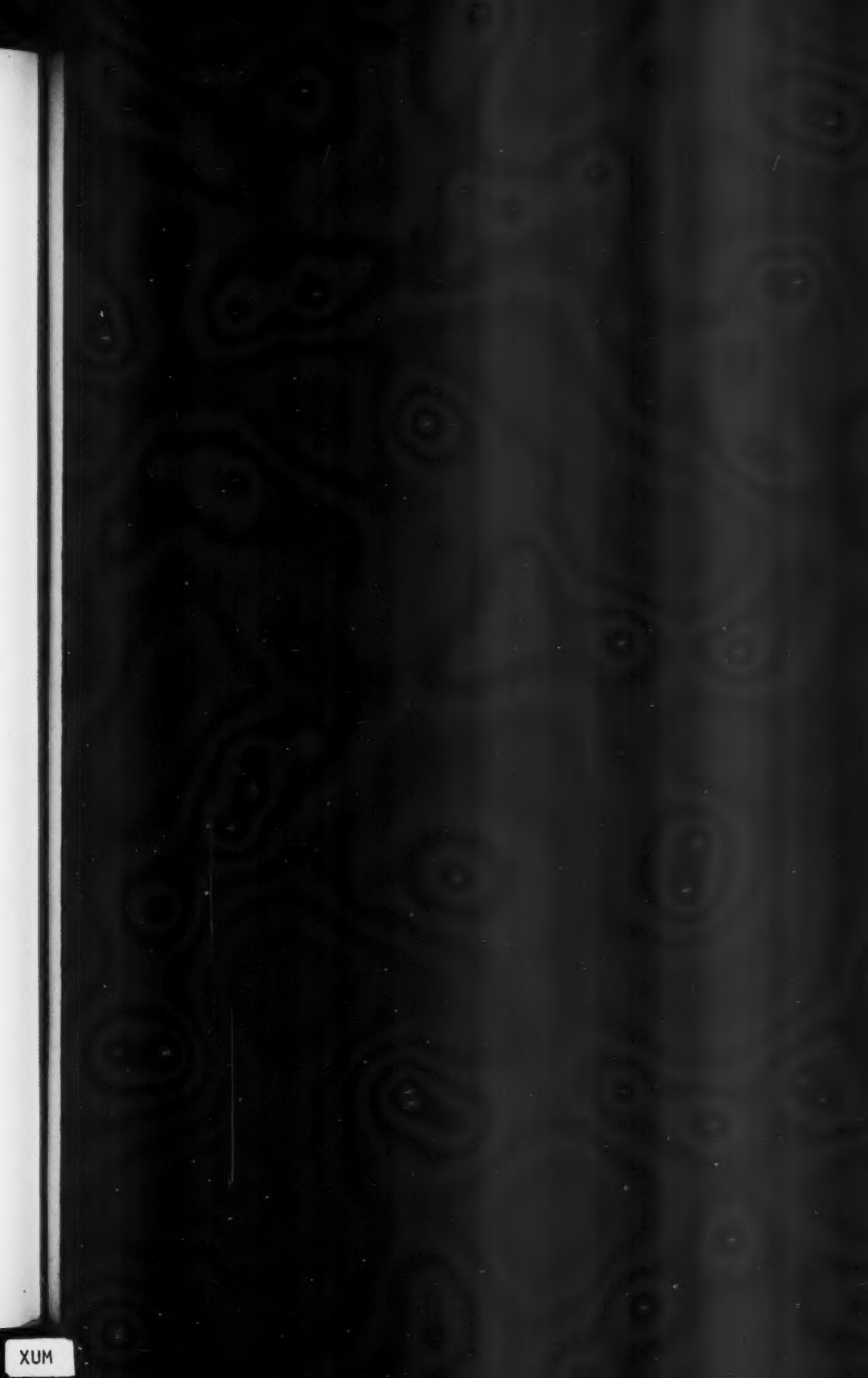
PLATE XIV.

FIG. 9.




Sirius.

Scale.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It seems difficult to believe that errors of observation alone can produce such symmetrical phenomena extending throughout all of the 29 yearly positions.

The only other explanation is that of perturbed motion caused by a third body in the system of Sirius.

Both the above characteristic peculiarities are satisfied by the assumption of an epicyclic path for the companion due to the revolution of either Sirius or its companion in a small orbit, with a period of about 100 years. By the method employed of plotting the observed positions of the companion, Sirius being the point from which the angles are laid off and the distances measured, any relative motion of Sirius itself in a nearly circular orbit would, on the drawing, appear to be transferred to the companion; changed however in phase by 180°, but with the direction of motion remaining the same.

After several trials on this supposition, the orbit shown in Fig 9 was the best obtained. The assumption is that the companion revolves with a period of about 100 years in a nearly circular apparent orbit of 0″.28 radius, as projected on the plane of the drawing. The direction of its apparent motion is contrary to the hands of a watch. The center of the small circular orbit describes around Sirius the ellipse shown, in accordance with the law of equal areas, in a period of 51 years.

This is by far the best orbit that the writer has yet succeeded in obtaining, and its superiority over the one shown in Fig. 8 is decided. The places for the years '65, '67, '68, '69, '70, '71, '78, '79, '83, '84, '85, '86, '89, '90, are practically in perfect agreement with the observations. If a mistake of 5 degrees has been made in the position angle for '88, this place also comes into close agreement with the observations. The small systematic discrepancy of about 1 degree in the position angle for the years '72, '73, '74, '75, is accidental, as a reference to the observations will show.

Thus the assumption of an epicyclic orbit satisfies the observed positions to a remarkable degree, even better than the trustworthiness of the observed positions would seem to warrant.

On the other hand the assumption of an elliptic orbit does not satisfy the observed positions to the extent that the trustworthiness of the observed positions would seem to warrant.

If epicyclic motion really exists it can be explained in two ways.

1st. The companion has a satellite. Roughly assuming the visible companion to revolve in an apparently circular orbit of 0″.28 radius about the center of gravity of the two bodies, in a

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period of 100 years, the mass of the satellite would be one ninth that of the companion, or one ninetieth that of Sirius. Its mean distance would be 3″ and at the present time its position angle from the companion would be about 80°, which would bring its apparent position close to Sirius.

2nd. Sirius has another companion. Assuming that it is Sirius that revolves in the small orbit, the mass of the second companion would be one twentieth that of Sirius and its mean distance would be 6″.5, which would make it one and one half times as far away as the known companion. At the present time its position angle would be about 260°. Its mass being one half that of the known companion, if their surfaces were equally luminous it would appear about 0.6 as bright and therefore easily seen. Still when it is considered that mass for mass the known companion cannot be $\frac{1}{1000}$ as luminous as Sirius (Young), it is plain that if this ratio should increase for this smaller and more distant companion it might exist with such small luminosity as to put it beyond the reach of existing telescopes. Its position on Jan. 1st, '94, '95, and '96, is shown on the right in Fig. 9. This supposition seems the most probable of the two. The apparent retrograde motion in either case would be caused by a great inclination of the orbit.

The reappearance of the Companion of Sirius, which may be expected to occur in a year or two, will be awaited with great interest: but whatever proves to be the true explanation of the systematic anomalies inherent in the present observed positions, the writer believes that this example proves the advantage of treating double star orbits by this graphical method.

ELEMENTS OF SIRIUS.

| | |
|---|---|
| Period in years | 50.99 |
| Periastron passage | 1894.59 |
| Inclination | 49° 8′ |
| Position of Node | 43° 21′ |
| Position of Periastron | 144° 39′ |
| Eccentricity | 0.557 |
| Semi-axis major | 7″.85 |

HARTFORD, CONN. April 27, 1894.

## THE VARIABLE PROPER MOTION OF PROCYON.

S. W. BURNHAM.

The micrometrical measures of double stars by Otto Struve, recently published in Volume X of the Poulkowa Observations,

* Communicated by the author.

include a long, continuous series of measures of the difference in declination of Procyon and two adjacent stars, commencing in 1851 and continuing each year, with few exceptions, down to 1890. These observations were made for the purpose of determining the amount, direction and character of the proper motion of Procyon, and particularly with reference to the question of the variability of that motion. It was long ago pointed out from meridian observations that Procyon had an irregular, sinuous motion in space similar to that of Sirius; and it was therefore inferred that it had a physical companion, the two revolving about their common centre of gravity, with a period of about forty years. Every effort has been made in the last twenty or more years to discover this supposed disturbing body. A number of imaginary stars have been recorded by different observers from time to time, but it is now conceded that none of these alleged companions had any real existence, and that if any such disturbing body exists at all, it has never been seen by the most powerful telescopes in use. On many nights during three or four successive years, I examined Procyon with the 36-inch at Mt. Hamilton under the most favorable circumstances, but always without seeing the least trace of any near star. It is probable that Procyon has been watched with the Poulkowa 30-inch for a much longer time, and presumably with the same negative result.

The companion stars selected by Otto Struve are: (B) $23^s.3$ preceeding, and 115″ north; and (C) $23^s.4$ following, and 67″ north. These stars are respectively D.M. (5°) 1738 (9.0) and 1741 (8.8). The star C (=W′ VII .990) is well known to double star observers as a close and difficult pair. In connection with the measures above referred to, and again on p. 130 of the same volume, where measures of the close pair are given, the discovery of this double star is erroneously credited to Dembowski by Otto Struve. As a matter of fact it was discovered independently in 1868 by Dembowski (A. N. 1979), but it had been previously seen by Frederick Bird of Birmingham in February, 1864, with a 12-inch reflector (*Astronomical Register*, Vol. I).

In the accompanying diagram Fig. 1, I have given the observed, corrected differences of declination between Procyon and these comparison stars. The upper horizontal scale refers to the observations of B, and the lower to C. As these stars are north of Procyon, both differences are increasing. The vertical scale on the left gives the date of the corresponding observations, but in order to have the positions of C directly opposite those of B of the same date, for convenience of comparing them with each

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other, the observed positions of C are shifted ten years down the time scale. The straight line through the positions of one star was drawn as accurately as possible to represent the observations, and then the line representing the positions of the other star was drawn parallel to it. It would appear that neither of these stars has any sensible proper motion of its own.

When we come to examine these positions of B and C, at first glance they seem to conform exceedingly well to simple rectilinear motion; but upon a more careful inspection it is seen that these positions lie with more or less regularity upon one side and then the other of any straight line which will best represent them as a whole. To be sure these differences are small, but there is no doubt of the fact that from some cause there is a substantial agreement in the measures of both stars with respect to this apparently irregular motion. In considering the weight of this affirmative evidence, it should be noted that the differences in the individual observations, of which means are here used, are in some of the years rather large for measures of this character, in certain instances amounting to as much as 0″.5. This is readily explained by the varying conditions under which the measures must have been made, and the uncertainty of the bisection of the large spurious disc of Procyon. As a further test of this matter, the differences of the corresponding measures of D and C are shown on the left of the diagram, the same scale as to time and declination applying to these as to the other positions. It is evident that these differences, if there were no errors in the measures, would be constant from first to last, or, if one or both of the comparison stars had any independent proper motion, the differences would increase or decrease regularly, and in any event the positions there laid down would lie in a right line. Without knowing what these positions represented, one could easily imagine that there was a periodic variation running through the series, but obviously this cannot be true, whatever may be the apparent indications.

I have not used the observed differences of R. A. between Procyon and B and C for the reason that the work with the micrometer should be much more accurate and reliable, and it would add but little to the evidence already submitted from the meridian observations. It would be of interest to present in graphical form all these apparent variations as shown by the work with the meridian circle so that the consistency and value of the data could be submitted to tests which cannot be applied to tabular results.

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PLATE XV. (FIG. 1.)

PROPER MOTION OF PROCYON.

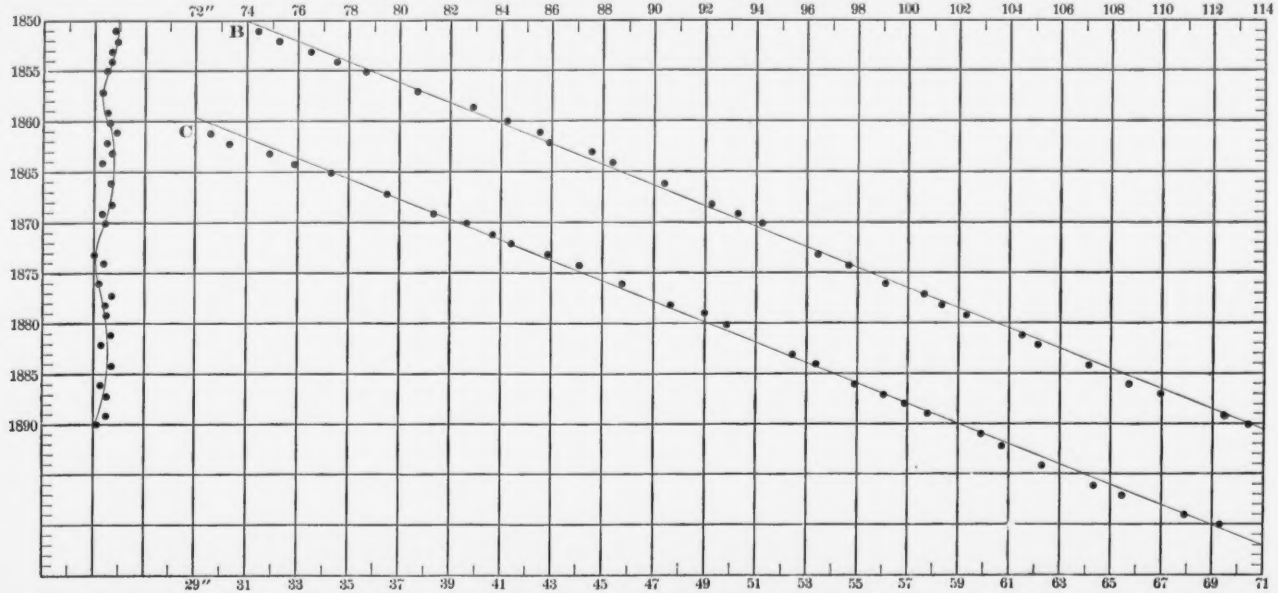
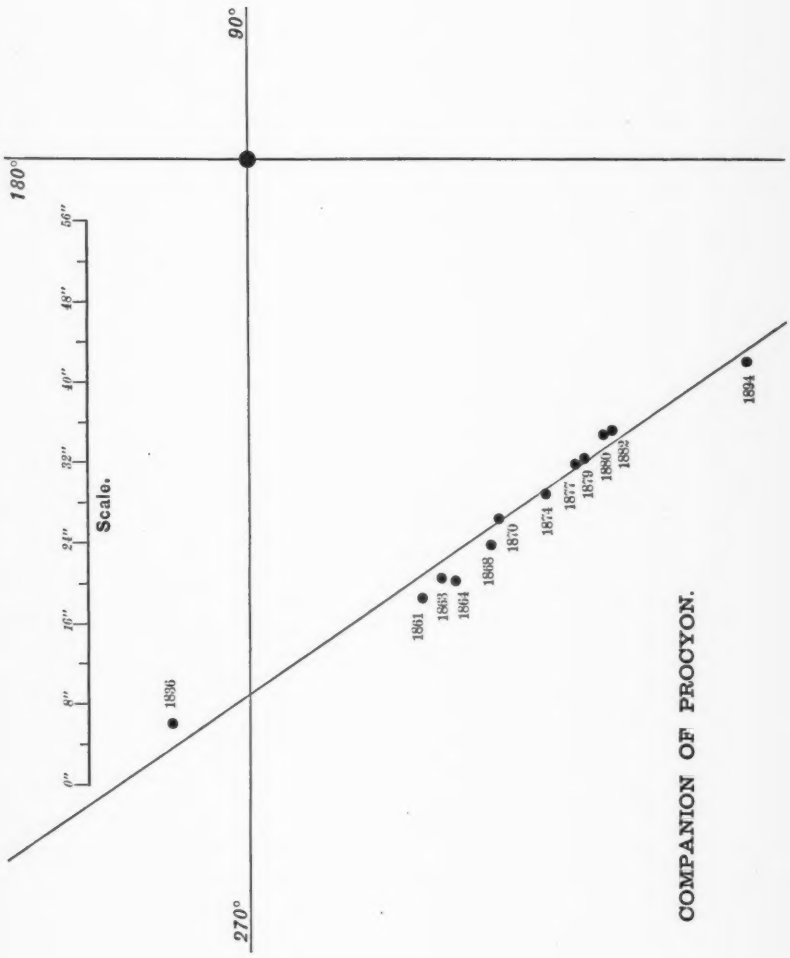


PLATE XVI. (FIG. 2.)



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In the diagram Fig. 2, I have given all the measured positions of the distant faint companion discoverd by Lamont in 1836. These measures commence with the year of discovery, and end with a careful set of measures on four nights by Professor Barnard with the 36-inch refractor at Mt. Hamilton in the early part of the present year. The line drawn through these positions is one showing the recognized direction of the proper motion of Procyon as derived from meridian observations, which is in the position-angle of 214°.6, the annual movement being 1″.245. It is certainly the fact that these observed positions cannot be well explained by simple rectilinear motion. They appear to lie on both sides of the line representing the path of the large star in space; and to some extent at least these observations tend to confirm the variations shown by the measures of B and C. On the other hand it should be remembered that this is a faint star, and difficult to measure with moderate apertures; and also that the observations preceding my own, which commence in 1877, are mostly on single nights, and therefore liable to more error in angle and distance than if each position was a mean of several observations. The motion from 1861 to 1894, assuming the angles to be substantially correct, would indicate an annual proper motion of 1″.19, which is not far from the value found from other observations. If we take the interval 1836-94, it gives about 1″.53, a value manifestly too large, and indicating considerable error in Lamont's angle.

While the proof of variable motion, so far as all these observations are concerned, is not as satisfactory as could be desired, it is at least of sufficient significance to make it important to continue the series of measures so long carried on by the distinguished Russian astronomer at the Poulkowa Observatory; and in this connection the Lamont companion should be measured at the same time, if the aperture used is sufficient for accurate results, in order to carry forward the measures already made for future comparison. It will be seen from the diagram that the distance is now increasing, and that hereafter this star will be more easily measured.

Chicago, April 9.

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**Determination of Geographical Longitudes by Photograph.**—In 1893 of *The Geographical Journal* will be found an interesting article on the above title.

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## RECENT OBSERVATIONS OF THE SATELLITES OF JUPITER.*

E. E. BARNARD.

ASTRONOMY AND ASTRO-PHYSICS for 1894, May, page 356, contains a letter from Professor E. S. Holden, director of the Lick Observatory, which bears the title, "Recent Observations of the Satellites of Jupiter." In this paper he notices some recent observations of mine that bore upon the forms of the discs of these moons, and especially with reference to the remarkable observations at Arequipa.

There are several points in the letter referred to that deserve attention, though why it was written it would be hard to tell, as it neither makes any attempt to verify the Arequipa observations nor to disprove my own.

In speaking of the results contained in my paper Professor Holden says: "In this respect his conclusions entirely agree with those of Professor Schaeberle previously printed in the Publications, A. S. P., Vol. V, p. 182, dated September, 1893."

As I have not seen the Publications of the Astronomical Society of the Pacific for some three years, I was unaware of Professor Schaeberle's results, mentioned by Professor Holden. As those results are important in their bearing on the question at issue, I have looked up the number of that journal referred to and will here copy Professor Schaeberle's paper in full.

### JUPITER'S SATELLITES.

"The August number of *l'Astronomie*, in commenting upon certain observations of Jupiter's satellites, made by the Arequipa observers asks whether the great Lick Observatory telescope could not for a time be devoted to this curious subject.

"Results of satellite observations made here by various observers have been published at various times, and from some personal observations of the conditions prevailing at Arequipa I have little hesitation in saying that for the same observer, the results given by the 13-inch telescope at Arepuipa can not equal those by the 36-inch on Mt. Hamilton; so that if it should finally turn out that certain marked peculiarities of the satellites had been observed at Arequipa which had not been observed here, this must be attributed to a superior diligence of the South American observers." J. M. S.

1893, September 1.

* Communicated by the author.

This is the paper to which Professor Holden refers and which was not known to me at the time of my observations.

I cordially agree with Professor Schaeberle's remarks.

I have conscientiously made my observations. I have made no record of the appearances of these satellites unless the conditions were favorable. I have given the time of each observation, so that they can be compared with theory. This has been done when my work on the new satellite necessarily directed my attention to the planet. What appearances these satellites may assume at other times than those I have noted in my paper, I do not hold myself responsible for.

The observations at Arequipa have attracted great attention from the astronomical world. They have brought up believers as well as unbelievers. It was absolutely necessary that some powerful telescope be brought into action to decide the question of the reality of the phenomena claimed at Arequipa. I have done this and am satisfied with the results.

Perhaps Professor Holden has some personal work on these moons with the great telescope that will be valuable in further settling this important question.

In reference to my paper on the transparency of the limb of Jupiter (A. AND A.-P. 124, April 1894, p. 272,) I have nothing to change in it. Professor Holden has (inadvertently I have no doubt) neglected to state the atmospheric conditions existing at the time of occultation of 47 Libræ, 1888, June 9. In my paper in A. AND A.-P., page 278, I have expressly stated that "when the seeing is bad there is a spurious limb to Jupiter that well might give the appearance of transparency at the occultation of a satellite."

By looking at page 64, Vol. VIII of the *Astronomical Journal* the observations of that occultation of 47 Libræ by both Professor Holden and myself will be seen.

The seeing was so bad in my case that I reduced the aperture of the 12-inch down to "8.1 inches as the images were too unsteady with full aperture." On a scale of 5 for perfect seeing, I stated the steadiness as 2.

In his paper on this occultation Professor Holden says, "Images, weight 2 (5 perfect; 1 very poor)" and again, "at Chron. time $14^h\ 12^m\ 35^s.2$ the star was entirely inside of the limb, but was still visible.

"The dark circle was no longer seen. For the next ten seconds or so, the star was alternately visible and invisible; the planet's limb was quite unsteady."

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The star was 3 hours and 35 minutes west of the meridian and 19° south of the equator, and with an altitude of only 15° to 20°.

Those who have attempted to observe Jupiter at low altitudes like this, will understand from the above notes that the conditions actually existed here for the production of an ill-defined and spurious limb to the planet, and the appearance of transparency was almost a necessary result of the existing conditions, so that really the observations proved nothing—except what was known and noted at the time, *i. e.*, that the seeing was bad.

Since the Publications of the Astronomical Society of the Pacific have been referred to by Professor Holden, I recall some observations that he himself has made proving the transparency of the limb of Jupiter with the great telescope, and as I wish to give both sides of this question a fair hearing, I will quote his own language as dictated to me in 1889. See *Pub. A. S. P.*, Vol. 1, No. 5, p. 104, where I say; "At a number of occultations of the satellites, I watched carefully for any evidences of their being seen through the edges of the planet, but saw nothing of the kind. *Professor Holden informs me, however, that, with the thirty-six-inch equatorial, the whole disc of a satellite has been visible within the planet's atmosphere* [limb], *at every occultation he has observed.*" The italics are mine.

It would be interesting to know the dates of these important observations, and the conditions of seeing at the time they were made.

From the above statements, it would seem that I have simply been unfortunate in not observing a satellite at the time Jupiter's limb was in a transparent condition.

In reference to the period of rotation of the Ist satellite, Professor Holden misstated my conclusions. He says, referring to the observations of Professors Schaeberle and Campbell: "In the same paper they conclude that the periods of axial rotation and of revolution of satellite I are equal. Dr. Barnard says that his observations (as yet unpublished) lead to a different result."

What I have stated in this connection, is contained in a paper in *Monthly Notices* of the Royal Astronomical Society, Vol, LIV, No. 3, p. 135, where I say, in speaking of a bright belt on this satellite:

"From peculiarities in the appearance of the belt, it is probable that the period of rotation on this axis is not coincident with the satellite's period of revolution about Jupiter.

"I have data in my hands now that will after a few more observations, perhaps, settle the inclination of the axis, and probably give us the period of rotation."

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These remarks were caused by an appearance of widening on the white belt, sometimes seen on the preceding and sometimes on the following side.

Certainly by observations of this phenomenon—if it is a fixed one—the period may be determined. I have therefore made no positive statement that this moon does not rotate on its axis once only during its revolution about Jupiter.

Indeed from the analogy of our own moon we would expect it to do so. Professor W. H. Pickering, however, gets a period $13^h\ 03^m\ 25^s.8$ upon the hypothesis of a direct rotation, and $13^h\ 03^m\ 10^s.8$ on the supposition that its rotation is retrograde, which he supposes to be the case. But as his results depend upon the very conditions that my observations negative, *i. e.*, the distortion of its disc, they cannot be considered proved.

The concluding remarks of Professor Holden are rather ambiguous.

"These few points from recent papers show very forcibly that everything is not yet settled with respect to Jupiter's satellite system and may serve to direct the attention of the possessors of large telescopes to some of the problems involved."

These same remarks will apply with equal certainty to every object in the entire heavens.

1894, May 10, Mt. Hamilton, Cal.

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## WEST INDIAN HURRICANES AND SOLAR MAGNETIC INFLUENCE.*

FRANK H. BIGELOW.

In the February number of ASTRONOMY AND ASTRO-PHYSICS, Professor H. A. Hazen submits a criticism on my suggestion regarding the recurrence of hurricanes in the 26.68 day solar period. It is perhaps desirable to indicate some erroneous steps in his discussion, upon which his negative conclusion was based.

1. He seeks to invalidate the data on which the hurricane recurrence curve was founded, namely Finlay's dates, in his *Hand-Book of Storm Tracks*, pp. 16, 19, as follows: "On examining more closely the material used, we are much surprised to find that 42 out of 80 cases are of North Atlantic storms, or storms above 45° north latitude, and which have no relation whatever to the tropical hurricanes we are supposed to be studying." Now Finlay specifies the 42 cases, which Professor Hazen

* Communicated by the author.

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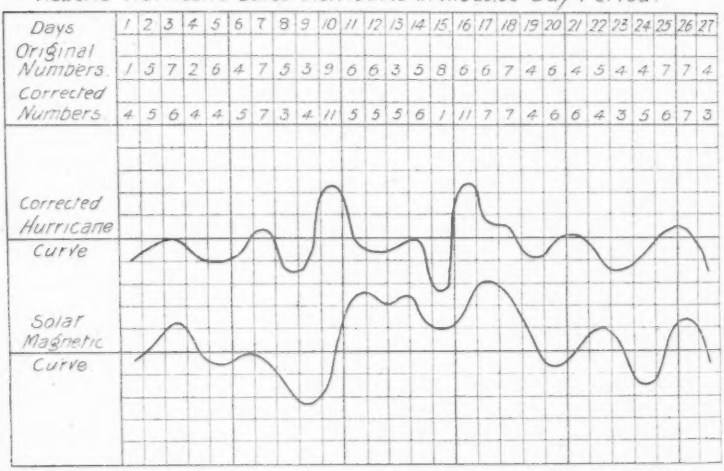
rejects, as those *charted*, and they are given on the chart as typical West Indian Hurricanes, so that the oversight is really that of the critic himself, and his point is invalid.

2. He seeks to substitute for Finlay's hurricane list of 80 cases a more extensive one of his own including 144 storms, A. AND A.-P., p. 108, and by distributing these in the 26.68 day period, he concludes that the curves of comparison are not synchronous. In making the distribution of dates in the period for years 1874 to 1893 inclusive, a systematic error in the use of the ephemeris itself has been introduced by Professor Hazen, which gives a false summary of the dates. This occurred as follows: The construction of the dates of the beginning of the successive periods, of the magnetic ephemeris, is such that the fractions of days greater than 50 hundredths, must not be called by the next integer day. Thus 15.78 is to be called day 15, and not day 16.

*Hazens Hurricane Dates distributed in the 26.68 Day Period.*




The error is not unnatural, and would not have occurred had Professor Hazen been familiar with the method of making the ephemeris. The effect of calling the dates one day too great at the beginning of the period, is to cause all the successive hurricanes of that period to be tabulated one day too late, and as this happens in about half of the periods, the error is accumulative in the results. The correct distribution gives the preceding relative numbers, which are also compared with those given by Professor Hazen, at the foot of page 108. The hurricane curve

is then platted from the corrected numbers, on a scale to be readily compared with my solar magnetic curve, which is placed beneath it.

The comparison of these curves, in connection with the Finlay curve, as given in the *American Meteorological Journal* for January, 1894, p. 382, shows that the extension of the dates from 82 (Finlay) to 144 (Hazen) has considerably improved the curve of hurricane recurrences. The marked discrepancy, to which Professor Hazen objects, at the 20th day of the period has disappeared.

It is hardly possible that two such peculiar curves as these, covering an interval of 20 years, should have come forth accidentally into this interesting agreement. My purpose in the original article was to call attention to a subject that needs elucidation, and to suggest that some light might be gained on the lines of research that are proving so fruitful in allied questions of meteorology. In my judgment, the outcome of Professor Hazen's labor is to strengthen the validity of this line of approach to the mechanism that originates the cyclones of the West Indies and the Gulf of Mexico.

## WEST INDIAN STORMS AND SOLAR MAGNETIC INFLUENCE.*

H. A. HAZEN.

The above effort to train my own guns upon me is quite interesting. On many accounts, I would prefer to leave the matter as in the February journal, as I am sure meteorologists in general will be enabled to see the fallacy in this later discussion. I desire, however, to make my own position a little clearer, and at the same time, aid some who may not see readily the exact nature of the above result. The whole subject is much farther reaching than appears on the surface and hence merits a careful study.

I now learn that the dates chosen by Professor Bigelow for his magnetic ephemeris are not civil dates, that is, from midnight to midnight, but the epoch is for the middle of the 24 hours, or practically for noon of each civil day. Of course this would make no difference, except to throw the curve half a day forward or toward the beginning of the period, if we only had enough observations. This will be seen by adding my numbers for "storms by number" two by two and comparing with Professor Bige-

* Communicated by the author.

low's latest set two by two, that is, the sum of my 1 + 2 equals almost exactly his 1 + 2, and my 2 + 3 equals his 2 + 3 and so on. Also if my curve of storms is compared with this latest one by Professor Bigelow it will be seen that there is really very little difference, in general only a single day in the crests and hollows.

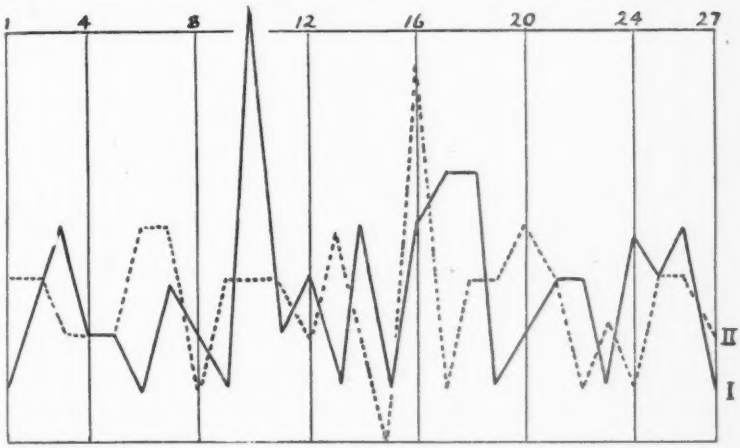
I cannot agree at all to the view that there is a close correspondence between the new curve of storms and the magnetic curve. On the 6th day there is a fall in the former and none in the latter, on the 7th the sharp rise in (1), (curve of storms) has a steady fall in (2), (magnetic curve), on the 8th there is a minimum in (1) which is reached in (2) on 9th, on the 10th there is a sharp maximum in (1) not found at all in (2), and the whole curve of (1) for the 11, 12, 13 and 14 days is totally different from (2), the sharp and long rise in (1) from 15 to 16 has no such condition in (2), the minimum in (1) on the 17th has a maximum in (2) and so on. It seems to me the curves are very dissimilar at almost every turn and throughout the whole rotation.

But this is not all. If we had a great many more observations of storms we could settle this matter once for all, it seems to me, however, that there are enough to give us an inkling of the truth. Suppose we divide my dates of storms into two equal groups and sum each group by itself, we shall then at once see whether this result is entirely fortuitous or whether there is a physical basis at the bottom of this supposed relation between magnetism and storms. The following are the figures in the groups doubled to make them comparable:

| Day of rotation | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group I. (73 storms) | 2 | 4 | 8 | 4 | 4 | 2 | 6 | 4 | 2 | 16 | 4 | 6 | 2 | 8 | 2 | 8 | 10 | 10 | 2 | 4 | 6 | 6 | 2 | 8 | 6 | 8 | 2 |
| II. (71 storms) | 6 | 6 | 4 | 4 | 4 | 8 | 8 | 2 | 6 | 6 | 6 | 4 | 8 | 4 | 0 | 14 | 2 | 6 | 6 | 8 | 6 | 2 | 4 | 2 | 6 | 6 | 4 |

The curves I and II show these figures graphically. Here we have about as good an illustration of a nonconformity as could be devised. In almost every crest or hallow in the one curve an opposite condition occurs in the other. It seems to one that nothing more could be desired to show how unreliable such a result as that obtained by Professor Bigelow is, and the great danger of relying on an apparent coincidence to prove a relationship between dissimilar phenomena.

I still think strongly that there is a most serious difficulty in the original fundamental magnetic curve. A treatment of the magnetic data in groups, as just given for storms, would very quickly show that there is no common thread running through the groups, and that the crests and hollows in the curve are




purely fortitious. I am also informed that in making up this fundamental mganetic curve the "disturbed days" were omitted. It seems to me that these days are the ones above all others to show the influence of magnetism on storms if there is one. Of course, in getting the diurnal swing of the magnetic needle, it is perfectly proper to omit all the 24 readings on any "disturbed day," as they do not enter into the diurnal range, and by taking out the whole day, the final result is not altered, but it is far otherwise in this case. To take out a *disturbed* day in a rotation period of 27 days is to take out the very day of all others to show this influence best. I think it is impossible to consider that there can be any magnetic influence from the Sun that goes through such extraordinary and rapid changes as those exhibited by the crests and hollows in this fundamental curve.

March 30, 1894.

## PROPER MOTION OF STARS IN THE DUMB-BELL NEBULA.*

E. E. BARNARD.

In the *Monthly Notices* of the Royal Astronomical Society for March, 1894, is a paper by Arthur A. Rambaut and W. E. Wilson on the Proper Motion of some stars in the Dumb-bell Nebula.

These gentlemen, from comparing measures of the stars on two photographs of this nebula (made by Mr. Wilson with a two foot reflector 1893, Sept. 3 and 8, with exposures of 27 minutes

* Communicated by author.

and 2 hours respectively) with measures of the same stars by Struve some forty-two years ago, find for those marked on their diagram *p*, *d*, *k*, *i*, *b'*, and *y*, proper motions of 4″.6, 3″.9, 5″.7, 6″.0, 5″.2, and 5″.3 respectively, covering the interval since Struve's work.

Observed Stars in the Dumb-bell Nebula.

These stars in the main are faint and require a good telescope to measure them satisfactorily.

To test the reality of these changes I have re-measured those of this list not too distant from the comparison star *a* with the 36-inch. The small stars were referred to *a* by position angle and distance. Following are the measures of *p*, *d*, *q*, and *a'*.

Position Angles and Distances Referred to *a*.

| | *q* | | | *p* | |
|---|---|---|---|---|---|
| 1894.347 | 257°.3 | 97″.51 | 1894.347 | 43°.9 | 83″.65 |
| .350 | 257°.1 | 96″.76 | .350 | 43°.7 | 83″.56 |
| 1894.348 | 257°.2 | 97″.13 | 1894.348 | 43°.8 | 83″.60 |

| | *a'* | | | *d* | |
|---|---|---|---|---|---|
| 1894.350 | 189°.5 | 58″.35 | 1894.347 | 84°.1 | 154″.06 |
| | | | .350 | 83°.9 | 154″.09 |
| | | | 1894.348 | 84°.0 | 154″.07 |

From these are derived the following $\Delta\alpha$ and $\Delta\delta$ for comparison as the measures in the above paper are referred to these coördinates.

$(* - a)$

| *q* | | *a'* | |
|---|---|---|---|
| $\Delta\alpha$ | $\Delta\delta$ | | |
| − 95″.12 | − 21″.44 | − 9″.63 | − 57″.55 |
| − 94 .32 | − 21 .61 | | |
| − 94″.72 | − 21″.52 | | |

| $p$ | | $d$ | |
|---|---|---|---|
| + 58″.00 | + 60.27 | + 153″.25 | + 15″.79 |
| + 57 .73 | + 60.41 | + 153 .22 | + 16 .27 |
| + 57″.86 | + 60.34 | + 153″.23 | + 16″.37 |

The following comparison will show the supposed changes since the time of Struve's observations.

| | $\Delta\alpha$ | $\Delta\delta$ | $\Delta\alpha$ | $\Delta\delta$ |
|---|---|---|---|---|
| | | | Differences from Struve. | |
| | | $q$ | | |
| Struve | − 97″.6 | − 20″.9 | | |
| Wilson | − 94 .4 | − 20 .6 | − 3″.2 | − 0″.3 |
| Barnard | − 94 .7 | − 21 .5 | − 2 .9 | + 0 .6 |
| | | $a'$ | | |
| Struve | − 12″.3 | − 57″.2 | | |
| Wilson | − 9 .6 | − 57 .5 | − 2″.7 | + 0″.3 |
| Barnard | − 9 .6 | − 57 .5 | − 2 .7 | + 0 .3 |
| | | $p$ | | |
| Struve | + 60″.6 | + 57″.9 | | |
| Wilson | + 56 .6 | + 60 .1 | + 4″.0 | − 2″.2 |
| Barnard | + 57 .9 | + 60 .3 | + 2 .7 | − 2 .4 |
| | | $d$ | | |
| Struve | + 152″.5 | + 12″.8 | | |
| Wilson | + 151 .5 | + 16 .6 | + 1″.0 | − 3″.8 |
| Barnard | + 153 .2 | + 16 .4 | − 0 .7 | − 3 .6 |

If we assume Struve's $\Delta\alpha$ and $\Delta\delta$ for the star $p$ to have been interchanged—and it looks very much as if they have—we find a very good accordance in the different measures of $p$ which would negative any motion in that star.

There seems, however, to have been some change in $q$, $a'$ and $d$ if Struve's distances are correctly given.

In their paper Messrs. Rambaut and Wilson call $d = a$ in magnitude. This is evidently a photographic effect due to the fact that $a$ is tinged with yellow, for it is very greatly brighter than $d$. Dr. Roberts photographs however, show $a$ decidedly the brighter.

I have assigned the following magnitudes to

| | |
|---|---|
| $a = 12$ mag. | $p = 15\frac{3}{4}$ mag. |
| $q = 14\frac{3}{4}$ " | $d = 14\frac{3}{4}$ " |
| $a' = 15\frac{1}{2}$ " | |

The magnitudes as given by Struve are

| | |
|---|---|
| $a = 10^m$ | $p = 13$ |
| $q = 11 - 12$ | $d = 11 - 12$ |

The appearance of the nebula in the great telescope is different from Dr. Robert's photographs of it only in the finer details.

I have examined Struve's original paper in *Philo. Trans.*, Vol. 151, part III, and find that his method of measuring the places of these stars was mainly by measuring position angles and with only a few direct distances from which the other distances were computed. Indeed no direct measures (referred to $a$) were made at all of any of the four stars under discussion. Not doubting the accuracy of the Struve results, yet it would have been more satisfactory if the distances had been directly measured. It might therefore, be well to withhold any opinion as to motion in these four stars until sufficient time elapses to show this motion by another series of measures compared with the present ones.

Mt. Hamilton, 1894, May 9.

# Astro-Physics.

## THE WOLF-RAYET STARS.*

W. W. CAMPBELL.

These observations of the Wolf-Rayet stars were begun in September, 1892, for the purpose of determining whether any relation existed between them and the new star in Auriga. The first examination of their spectra resulted in the finding of a large number of new bright lines and bands whose wave-lengths could be determined very accurately with our apparatus. In view of the very general interest taken by spectroscopists in bright-line spectra,—a fact shown by the frequency with which even the approximate wave-lengths of the few known lines and bands are quoted,—I decided to investigate these stars as completely as possible. The observations were practically finished in July, 1893.

The stars of this type are characterized by bright bands, and in some cases by bright lines and bands superposed upon their strong continuous spectra. Many are further marked by the presence of absorption bands of different intensities and breadths, and in several I have found dark lines. While many of these spectra differ widely from each other in appearance, and a few present almost no points of resemblance, yet they all fall readily into one class, distinctly separate from every other known type.

The first three of these stars were discovered by MM. Wolf and Rayet, in 1867 at the Paris Observatory, in the constellation Cygnus.

M. Respighi, in 1871 at Madras, found that $\gamma$ Argus has a similar spectrum.

Professor E. C. Pickering discovered three others, at Cambridge, while sweeping for gaseous nebulæ with a telescope provided with a spectroscopic eye-piece.

By the same method Dr. Copeland, at Puno, Peru, detected five more; and at Dun Echt, using an object-glass prism, he found a sixth.

The astronomers of Harvard College Observatory have the great credit of discovering forty-two stars of this type since 1888. They were found, for the most part by Mrs. M. Fleming, by means of the bright bands in their photographed spectra on the Henry Draper Memorial plates. The photographs were made at Cambridge and in Peru.

* Communicated by the author.

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## Table I.—List of known Wolf-Rayet Stars.

| No. | Star. | Mag. | R.A (1900) | Dec. (1900) | Gal. Long. | Gal. Lat. | Discovered by |
|---|---|---|---|---|---|---|---|
| | | | h m | ° ′ | ° ′ | ° ′ | |
| 1 | DM. + 63°83 | 9·5 | 0 37·5 | + 64 14 | 89 53 | + 2 14 | H. C. O. |
| 2 | DM. + 56°686 | 9·1 | 2 33·9 | + 56 18 | 105 21 | − 2 18 | " |
| 3 | DM. + 56°731 | 9·5 | 2 44·8 | + 56 31 | 106 37 | − 1 26 | " |
| 4 | Cord. G. C. 8631 | 7·2 | 6 50.0 | − 23 48 | 202 19 | − 8 52 | P. |
| 5 | γ Argus | 3 | 8 6.5 | − 47 2 | 230 20 | − 6 59 | R. |
| 6 | Cord. Z. C. 8h4141 | 9 | 8 51.6 | − 47 12 | 235 13 | − 1 4 | C. |
| 7 | " G. C. 13554 | 8½ | 9 51.6 | − 57 15 | 248 43 | − 2 19 | H. C. O. |
| 8 | —— | — | 10 6.1 | − 62 5 | 253 0 | − 5 14 | " |
| 9 | —— | — | 10 7.6 | − 60 8 | 252 4 | − 3 30 | " |
| 10 | —— | — | 10 13·3 | − 57 24 | 251 14 | − 0 48 | " |
| 11 | —— | — | 10 14.4 | − 62 9 | 253 51 | − 4 46 | " |
| 12 | —— | — | 10 22.9 | − 58 8 | 252 42 | − 0 46 | " |
| 13 | Cord. G. C. 14626 | 7.2 | 10 37.4 | − 59 9 | 254 51 | − 0 46 | " |
| 14 | " Z. C. 10h2684 | 9 | 10 37.8 | − 58 15 | 254 29 | + 0 4 | C. |
| 15 | " G. C. 14684 | 6.9 | 10 40.1 | − 59 36 | 255 21 | − 1 1 | H. C. O. |
| 16 | " " 14691 | 8½ | 10 40.3 | − 59 12 | 255 48 | − 0 40 | " |
| 17 | —— | — | 10 43.4 | − 58 41 | 255 20 | − 0 1 | " |
| 18 | —— | — | 10 47.9 | − 61 46 | 257 5 | − 2 36 | " |
| 19 | Cord. G. C. 14965 | 8½ | 10 52.0 | − 59 51 | 256 49 | − 0 38 | " |
| 20 | —— | — | 10 55.8 | − 57 17 | 256 16 | + 1 56 | " |
| 21 | Cord. G. C. 15220 | 8.2 | 11 2.3 | − 64 58 | 259 53 | − 4 53 | " |
| 22 | " " 15305 | 8 | 11 5.8 | − 60 26 | 258 38 | − 0 31 | C. |
| 23 | —— | — | 11 55·2 | − 54 33 | 263 29 | + 6 53 | H. C. O. |
| 24 | Cord. G. C. 17840 | 6 | 13 1.7 | − 64 46 | 272 19 | − 2 51 | " |
| 25 | —— | — | 13 11.5 | − 57 36 | 274 13 | + 4 8 | C. |
| 26 | —— | — | 13 24·3 | − 61 34 | 275 15 | − 0 1 | H. C. O. |
| 27 | —— | — | 13 36·3 | − 66 55 | 275 30 | − 5 31 | " |
| 28 | Cord. Z. C. 15h934 | 9 | 15 15.9 | − 62 20 | 287 4 | − 5 34 | " |
| 29 | —— | — | 15 55.0 | − 62 28 | 290 34 | − 8 28 | " |
| 30 | Cord. Z. C. 15h4129 | 8½ | 16 0.6 | − 25 57 | 290 39 | + 17 39 | " |
| 31 | " G. C. 22748 | 5·9 | 16 44.5 | − 41 4 | 311 20 | + 0 44 | " |
| 32 | " " 22763 | 7·5 | 16 45·3 | − 41 41 | 310 56 | + 0 14 | " |
| 33 | " " 22827 | 7 | 16 47·3 | − 41 40 | 311 11 | − 0 3 | C. |
| 34 | " " 22838 | 8.2 | 16 47.9 | − 44 50 | 308 47 | − 2 ·7 | H. C. O. |
| 35 | " " 22843 | 6.4 | 16 48.0 | − 41 0 | 311 47 | + 0 17 | " |
| 36 | " " 23072 | 6.5 | 16 57.0 | − 38 0 | 315 13 | + 0 45 | " |
| 37 | " " 23073 | 7·1 | 16 57·2 | − 37 42 | 315 29 | + 0 55 | " |
| 38 | " " 23416 | 7.2 | 17 12.1 | − 45 32 | 310 47 | − 5 57 | " |
| 39 | " Z. C. 17h3612 | 9 | 17 55·1 | − 32 42 | 326 8 | − 6 15 | " |
| 40 | SDM. − 19°4854 | 9.6 | 18 2.1 | − 19 25 | 338 33 | − 1 54 | " |
| 41 | " − 21°4864 | 7.8 | 18 2.5 | − 21 16 | 336 56 | − 2 5 | P. |
| 42 | " − 11°4593 | 8.7 | 18 13·5 | − 11 40 | 347 36 | + 0 35 | H. C. O. |
| 43 | DM. + 30°3639 | 9·3 | 19 30.9 | + 30 19 | 32 26 | + 3 57 | " |
| 44 | " + 35°3953 | 7·0 | 20 2.2 | + 35 31 | 40 20 | + 1 10 | " |
| 45 | " + 35°4001 | 8.5 | 20 6.5 | + 35 53 | 41 8 | + 0 39 | W.-R.1 |
| 46 | " + 35°4013 | 8.0 | 20 8.2 | + 35 54 | 41 20 | + 0 24 | " 2 |
| 47 | " + 37°3821 | 7·1 | 20 8.4 | + 38 3 | 43 7 | + 1 35 | C. |
| 48 | " + 36°3956 | 8.0 | 20 10.8 | + 36 21 | 42 1 | + 0 13 | W.-R.3 |
| 49 | " + 36°3987 | 8.1 | 20 13·3 | + 37 7 | 42 56 | + 0 15 | P. |
| 50 | " + 38°4010 | 8.7 | 20 15.8 | + 38 25 | 44 16 | + 0 37 | H. C. O. |
| 51 | " + 43°3571 | 7·5 | 20 17·1 | + 43 32 | 48 32 | + 3 27 | " |
| 52 | " + 36°4028 | 9·5 | 20 17.8 | + 36 36 | 43 2 | − 0 46 | " |
| 53 | " + 55°2721 | 8.9 | 22 15.0 | + 55 37 | 70 29 | − 0 50 | " |
| 54 | —— | 10 | 22 23.7 | + 55 46 | 71 38 | − 1 20 | " |
| 55 | DM. + 56°2818 | 8.9 | 22 32.9 | + 56 23 | 73 3 | − 1 25 | " |

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The fifty-five Wolf-Rayet stars now known are arranged in the order of their right accensions in Table I, with their catalogue numbers and magnitudes in the second and third columns. The anonymous star No. 54 was observed here, and I estimated its magnitude at 10. The discoverer of each star is noted in the last column. (W.-R. = Wolf-Rayet; R. = Respighi; P. = Pickering; C. = Copeland; H. C. O. = Harvard College Observatory.)

Professor Pickering has pointed out* that all these stars are near the central line of the Milky Way, and have a tendency to occur in groups. By assuming the position of the North Pole of the Galaxy at the year 1900 to be in Right Ascension $12^h\,40^m$ and declination $+ 28°$, and measuring the longitudes northward from the ascending node (in right ascension $18^h\,40^m$ and declination $0°$) he found for the galactic longitudes and latitudes of these stars the results given in the 6th and 7th columns. It will be seen from the column of latitudes that all but six are within $6°$ of the central line of the Milky Way; only one, No. 30, is more than $9°$ from the central line; and that one is, moreover, in a projecting spur of the Milky

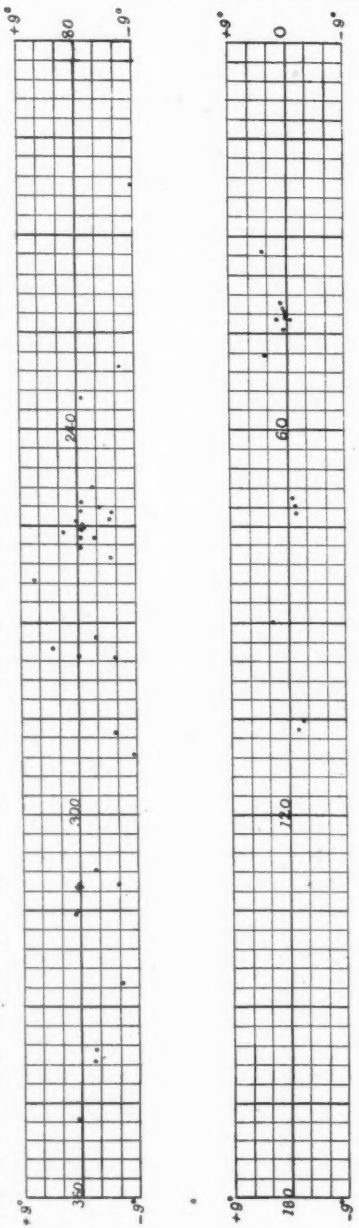


Fig. 1.—Distribution of the Wolf-Rayet Stars in the Milky Way.

* *Astronomische Nachrichten*, No. 3025.

Way. But the remarkable distribution of these stars is shown best by the accompanying chart (Fig. 1), on which the black dots representing them have been plotted by means of their galactic coördinates. The upper half represents the Milky Way south of the equator, and the lower half the Milky Way north of the equator. It extends only 9° each way from the galactic circle, and star No. 30 is necessarily omitted. In addition to the three well defined groups, made up of the stars numbered 31–38, 7–22 and 43–52, there are a few minor groups. An unduly large number, thirty-nine, are in the southern hemisphere, and only sixteen in the northern. Attention should also be called to the preference of these stars for two large and nearly opposite regions of the Milky Way, and their avoidance of the two equatorial regions, which can not be attributed to incompleteness in the observations for detecting them.

Thirty-two stars of this type are visible at Mt. Hamilton; but many of these are near the southern horizon at meridian passage and can be observed only at a great disadvantage. $\gamma$ Argus, of the 3d magnitude, is the only bright one. A few other stars very far south are of the sixth magnitude. But unfortunately all those in good position for observing with the 36-inch telescope are between the 7th and 10th magnitudes: so that practically this investigation has been limited to the spectra of the faint stars of this class.

The visual determinations of the positions of the star lines are based upon micrometer comparisons with near lines in the artificial spectra of copper, hydrogen, iron, lead, magnesium, mercury, zinc, etc. Rowland's wave-lengths of the artificial lines were employed, in so far as he has given them; and the positions of the others I determined by direct micrometer comparison with Rowland's lines in the solar spectrum, using second and third order spectra. The wave-lengths are therefore based upon Rowland's scale.

Each night's observation of a line consisted in making, on an average, five readings each on the star line and artificial line. The positions of all the lines and bands visible in the thirty-two stars have been measured as accurately as possible, and nearly all have been observed on two or more nights. For the most part the observations were made with a 60° dense flint prism dispersing 5½° between B and H$\varepsilon$, and a magnifying power of 13. With this prism and eye-piece I am just able to separate the two components of the double solar line at $\lambda$ 4891, which are about 0.7 tenth-metre apart. Occasionally a strongly dispersing compound

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prism, or a first or second order grating, or a magnifying power of 26, would be employed. Very often, even in the case of the brightest lines, no gain of accuracy was made by using the higher dispersion, on account of the great width of the lines and the consequent difficulty of estimating their centres.

The photographic observations were made with the 60° prism and 10½-inch camera. The hydrogen comparison spectrum was photographed on each plate, on both sides of the star spectrum, at about the time when the exposure on the star was half completed. Stronger dispersion would have been desirable in studying some parts of a few of the spectra; but in many cases it would have been a positive disadvantage, owing to the great width of the bright bands: the increased width of the bands, due to higher dispersion, would require increased exposure-times, and would not yield corresponding increase of accuracy in measurements. Further, the Observatory does not yet possess a spectroscope of rigid construction for photographic work. Our present instrument lies almost wholly in one plane; and while serving its original purpose admirably, the flexure during the long exposures required for these faint stars is sufficient to introduce slight errors of wave-length, broaden the lines, and injure the definition. For this reason, a number of bands suspected of being double and multiple are left in doubt. Nevertheless, it has been considered profitable to secure one negative of each spectrum, and twenty-four have thus far been photographed. As is well known, the chromatic aberration in a large visual telescope is very marked in the blue and violet. Such is the case with the 36-inch equatorial. Light of only one given wave-length enters the spectroscope properly for any given position of the slit. I am able, therefore, to photograph only a very limited part of a stellar spectrum at one time. A few of the photographs of these spectra extend from H$\beta$ to near H$\varepsilon$; but the greater number do not extend above $\lambda$ 420.

The photographic results must be considered, for the above reasons, as incomplete and provisional, and I hope to secure another set at some future time with a suitable spectroscope.

The thirty-two stars observed are arranged in the order of their right ascensions in the following tables. Under each star are the collected results for the several bright lines and bands in its spectrum, both visual and photographic. Each wave-length recorded to four or five places is the result for one night's work on that line; and on the average depends, as stated above, upon five micrometer comparisons. The visual determinations for the

several nights appear in vertical columns, and their means are taken.

Very few of the lines are monochromatic images of the slit. They are, with few exceptions, more or less broad and ill-defined bands, brightest at the centre, and shading off sometimes rapidly, again gradually, in both directions. In a few cases the bands are unsymmetrical. Two extreme cases are found in the stars D.M. + 30° 3639 and + 43° 3571. The lines in the former are nearly all narrow and some are monochromatic; while in the latter star they are abnormally broad and somewhat unsymmetrical.

The intensities of the lines are indicated in a general way by means of symbols under the numbers representing their wave-lengths. Thus, ++ signifies "very bright"; + signifies "bright;" those "easily measurable" are unmarked; the "difficult" lines are marked thus —; while for those too faint to justify micrometer measures, and for some "measurable" or "difficult" lines which are "very bright" in a number of other stars, the results are given in three figures.

The visual intensity curves of these thirty-two stars were constructed in my note-books twice, on the average, for each star. It is impracticable and unnecessary to reproduce them all, and I have selected for reproduction the four shown on Figure 2. They are typical of nearly all the spectra, but of course are far from representing all the variations in the relative intensities of the bands. The photographic intensity curves of four stars are shown on Figure 3, but they are seriously modified, it must be remembered, by chromatic aberration.

The spectra of these stars did not seem to me to be relatively faint in the blue and violet. The continuous spectra were usually visible up to H$\delta$; which, considering the magnitudes of the stars, is as far as we would expect to follow them. Some of the spectra, notably that of $\gamma$ Argus, seemed unusually strong in the blue and violet.

The dark absorption bands were observed by noting them in the intensity curves. A large number of the stars show no traces of the broad absorption bands, several others show them slightly; in a few the absorption is plainly visible, and in a few it is marked. On the whole, the absorption is much less than I had expected to find it. While much of the effect is real, some of it is undoubtedly due to contrast between faint continuous spectrum and very bright bands. Nearly all the strong absorption bands noted by me lie on one or both sides of the strong bright bands $\lambda$ 581 and $\lambda$ 569 in the yellow, and of the very strong bright

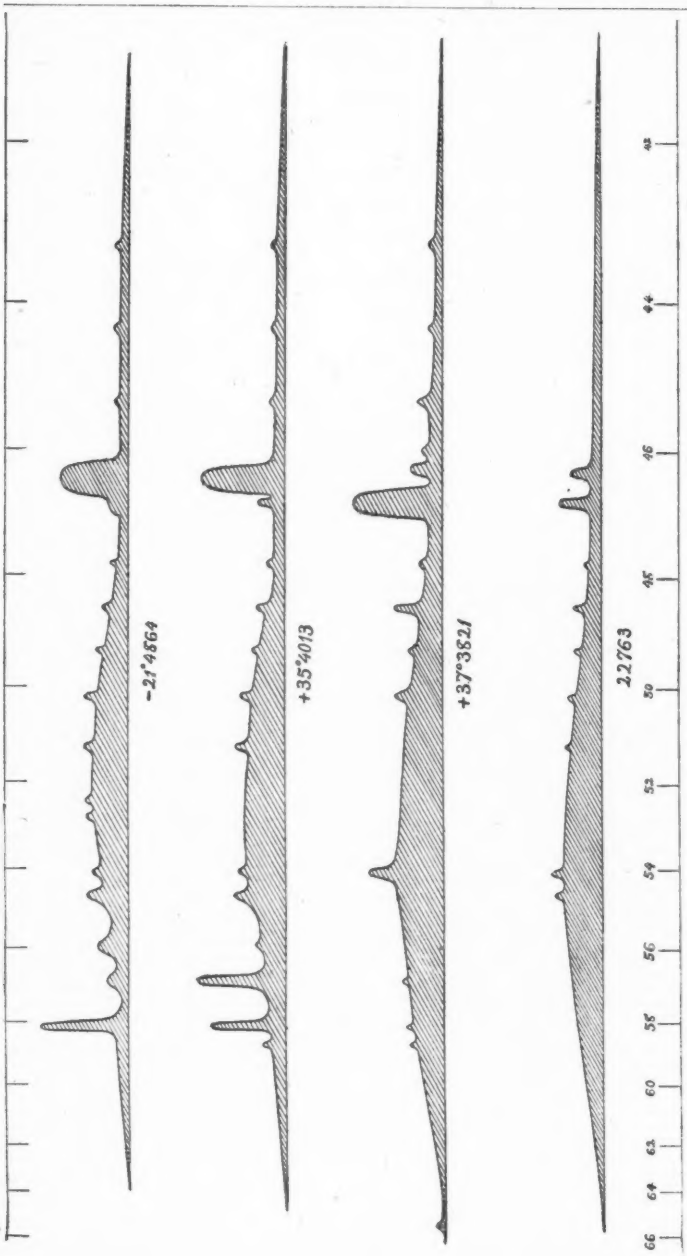



FIG. 2.—VISUAL INTENSITY CURVE OF THE WOLF-RAYET STARS.

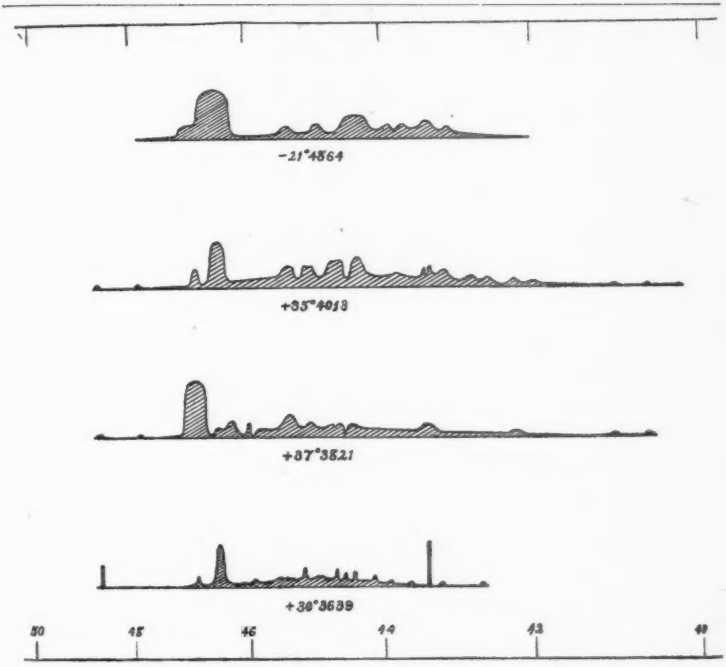



FIG. 3.—PHOTOGRAPHIC INTENSITY CURVE OF THE WOLF-RAYET STARS.

bands λ 469 and λ 465 in the blue. They do not admit of accurate observation.

No. 1. DM. + 63° 83.

| | | | | Hβ | | | |
|---|---|---|---|---|---|---|---|
| 581 | 5413.0 | 5023 | 4938 | 4861 | 4688.2 | 4615 | 454 |
| ..... | 5413.5 | ..... | ..... | ..... | 4687.9 | 4614 | ..... |
| ..... | 5411.9 | ..... | ..... | ..... | 4687.5 | 4615 | ..... |
| ..... | 5412.6 | ..... | ..... | ..... | 4686.4 | ..... | ..... |
| ..... | ..... | ..... | ..... | ..... | 4685.3 | ..... | ..... |
| 581 | 5413 | 5023 | 4938 | 4861 | 4687 | 4615 | 454 |
| − | + | − | − | − | ++ | − | − |

Photographic: 4688, 4615, 454.
++ +

Negative under-exposed. The band 469 is about 40 tenth-metres broad.

No. 2. DM. + 56° 686.

| | | | | | | | | Hβ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5814.2 | 5690.0 | 5590.8 | 5472 | 5414 | 526 | 5126 | 5020 | 4861 | 4787 | 469 | 4653.6 | 4534 |
| 5813.4 | 5692.4 | 5598.0 | ..... | 5411 | ..... | 5125 | 5020 | ..... | ..... | ..... | 4653.2 | 4535 |
| ..... | ..... | ..... | .... | ..... | ..... | 5121 | 5021 | ..... | ..... | ..... | 4653.2 | ..... |
| 5814 | 5691 | 5594 | 5472 | 5412 | 526 | 5124 | 5020 | 4861 | 4787 | 469 | 4653 | 4534 |
| ++ | | | − | − | | − | | − | − | | ++ | − |

No photograph taken. The band 465 unites with and overlaps a fainter band at 469, as in the star No. 41, S DM. — 21° 4864. [See Fig 2].

No. 3. DM. + 56°731.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5810.1 | 5690 | 5594 | 5470 | 5411.2 | 469 | 4654 | 454 |
| 5812.3 | 5692 | 5594 | ..... | 5410.8 | ..... | 4652 | ..... |
| 5813.8 | ..... | ..... | ..... | ..... | ..... | 4656 | ..... |
| 5811.8 | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 5812.8 | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 5812 | 5691 | 5594 | 5470 | 5411 | 469 | 4654 | 454 |
| + + | | | − | | | + + | |

No photograph taken. The band at 465 unites with and overlaps the fainter band 469, as in the preceding star.

No. 4. Cord. G. C. 8631.

| Hα | $D_3$ | | | | | | Hβ | | | | | | Hγ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6563 | 588 | 5807 | 569 | 559 | 5471 | 5418 | 4944 | 4860 | 4789 | 4688 | 4614 | 4545 | 4343 |
| ..... | ..... | 5803 | ..... | ..... | ..... | 5413 | 4944 | 4863 | ..... | 4688 | 4613 | 4544 | 4342 |
| ..... | ..... | 5809 | ..... | ..... | ..... | 5416 | 4940 | 4863 | ..... | 4687 | 4614 | ..... | ..... |
| ..... | ..... | 5808 | ..... | ..... | ..... | 5415 | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| ..... | ..... | ..... | ..... | ..... | ..... | 5416 | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| ..... | ..... | ..... | ..... | ..... | ..... | 5415 | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 6563 | 588 | 5807 | 569 | 559 | 5471 | 5416 | 4943 | 4862 | 4789 | 4688 | 4614 | 4544 | 4342 |
| − | | | | | − | + + | | + | | + + | + | + | |

Photographic: 4688, 4628, 460, 454, 451, Hγ, 420, Hδ. Exposure too short.
+ + + + + + + + +

The band observed visually at 4614 is shown by the photograph to consist of two, at 4628 and 460. This spectrum is almost identical with that of + 37°3821 and + 35°4001.

Pickering, with the 15-inch Cambridge refractor in 1881, observed three bright lines in this spectrum at 545, 486 and 466.—*Nature*, Vol. 23, p. 604.

Vogel, at Potsdam in 1882, observed four bright lines in this star, as follows: 581, faint; 540, bright; 485, very faint, probably identical with the hydrogen line, Hβ; 469, bright, very broad.—*Publ. Potsdam*, Vol. 4, p.17.

No 5. γ Argus.

| Hα | $D_3$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 6563.1 | 5875.8 | 5814.1 | 5694.7 | 5596 | 5411 | 4689.6 | 4751.4 | 4440.2 |
| 6563.8 | 5873.5 | 5813.8 | 5695.1 | .... | ..... | 4689.0 | 4650.6 | 4441.4 |
| 6567.1 | 5872.1 | 5812.9 | 5692.8 | ..... | ..... | 4689.0 | 4651.2 | 4441.6 |
| ..... | 5874.9 | 5809.* | 5693.* | ..... | ..... | 4688.0 | 4650.2 | ..... |
| ..... | 5874.6 | 5812.5 | 5695.7 | ..... | ..... | 4688.0 | 4649.2 | ..... |
| 6565 | 5874 | 5813 | 5694 | 5596 | 5411 | 4689 | 4651 | 4441 |
| + | + | + + | + + | − | − | + | + + | + |

* Hasty measures.

Photographic: Exposures on ordinary dry plates show bright lines at

| 4787 | 4688 | 4651 | 454 | 4517 | 4504 | 4480 | 4467 | 4442 | 432 | 4270 | 4227 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | + | ++ | | | | + | + | ++ | | | |

They show H$\gamma$, H$\delta$, H$\varepsilon$ to be dark, with no signs of bright edges, such as would exist if the lines were doubly reversed. The visual observations show H$\alpha$ to be quite bright, with no signs of reversal. Two negatives show what seems to be a very faint band at H$\beta$, with a fine partially dark line through its center at 4861; but the contrasts are very slight indeed. Photographs on isochromatic plates show all the bright bands observed visually except H$\alpha$, and additional ones at 5470, 5135, 5020, 494, 4787. There appears to be a dark line at 4473, between the bright bands 4480 and 4467, possibly coincident with the bright chromosphere line 4472.

I believe that this is the first spectrum in which the H$\alpha$ line has been observed to be bright and the other hydrogen lines dark. The blue and violet regions of this spectrum are relatively very bright, and the continuous spectrum is visible to K. The altitude of $\gamma$ Argus when on our meridian is less than 6°.

A visual intensity curve of this spectrum was published by me in ASTRONOMY AND ASTRO-PHYSICS for June, 1893.

Respighi observed a few bright lines in this star at Madras in 1871, but did not identify them.—*Comptes Rendus*, Vol. 74, p. 516.

Ellery, at Melbourne in 1879, observed bright lines at 5760, 5648, 4682.—*Observatory*, Vol. 2, p. 418.

Copeland, at Puno, Peru, in 1883, observed three intensely bright and strong lines at 5809, 5668, 4646, and a slender bright line at 590.—*Copernicus*, Vol. 3, p. 205.

No. 6. Cord. Z. C. $8^h$ 4141.

| | | | | H$\beta$. | | | |
|---|---|---|---|---|---|---|---|
| 5812.0 | 5690 | 559 | 542 | 4862 | 4690.1 | 4649.3 | 454 |
| 5814.5 | ..... | ..... | ..... | ..... | 4690.3 | 4652.4 | ..... |
| 5813.1 | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 5813. | 5690 | 559 | 542 | 4862 | 4690 | 4651 | 454 |
| + | | | | | | ++ | |

No photograph taken. The altitude of this star on the meridian is less than 6°. I have identified it as Cord. Z. C. $8^h$ 4141, 9th magnitude.

Copeland, at Puno in 1883, observed a fairly bright line at 573 and an intense one at 4636.—*Copernicus*, Vol. 3, p. 206.

No. 25. Anonymous.

Copeland, at Puno in 1883, observed this to be a 9th magnitude star, with bright lines in its spectrum at 5753, 4643.—*Copernicus*, Vol. 3, p. 206.

No. 30. Cord Z. C. 15$^h$ 4129.

5133 4942 4687
— —

These lines very faint and broad. No photograph taken.

No. 31. Cord G. C. 22748.

4690
—

Photographic: 4689, 4637.
+ +

The H$\gamma$ and 4473 lines are narrow, dark, with borders slightly brightened, probably double-reversed. There are dark lines at 454 and 451.

No. 32. Cord G. C. 22763.

| | | | | | H$\beta$ | | | |
|---|---|---|---|---|---|---|---|---|
| 5573.2 | 5411.8 | 5132 | 5022 | 4941 | 4861.1 | 4785.4 | 4685.4 | 4637.2 |
| 5472.3 | 5413.4 | 5134 | ..... | ..... | 4860.1 | 4784.4 | 4686.1 | 4637.3 |
| ..... | ..... | ..... | ..... | ..... | 4861.6 | ..... | 4686.8 | 4638.7 |
| ..... | ..... | ..... | ..... | ..... | ..... | ..... | 4688.0 | 4637.5 |
| 5473 | 5412 | 5133 | 5022 | 4941 | 4861 | 4785 | 4687 | 4638 |
| — | + | — | — | — | + | — | ++ | ++ |

Photographic: 4690, 4638, 4543, 4515, 4473, 4340.
+ + +

The band at 4638 is more prominent than in any of the other stars containing it, and admitted of very accurate observation.

The visual intensity curve for this spectrum is given on Fig. 2.

No. 33. Cord G. C. 22827.

| D$_3$ | | | | | | H$\beta$ | | | |
|---|---|---|---|---|---|---|---|---|---|
| 588 | 5812.8 | 5694.0 | 559 | 5474.0 | 5413.9 | 4863.5 | 4785 | 469 | 4653.4 |
| ..... | 5809.4 | 5692.5 | ..... | ..... | ..... | ..... | ..... | ..... | 4652.3 |
| ..... | 5813.1 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 4652.0 |
| 588 | 5812 | 5693 | 559 | 5474 | 5414 | (4863) | 4785 | 469 | 4653 |
| | ++ | + | | — | | — | — | | ++ |

Photographic: 469, 4652.
+ ++

H$\gamma$ is dark, narrow, with bright borders, and is probably double-reversed.

The very faint and difficult line observed visually at (4863) is

probably one of the borders of a doubly reversed H$\beta$. The band 469 is too faint to observe accurately visually.

Copeland, at Puno in 1883, observed bright lines at 5809, 5692, 4651.—*Copernicus*, Vol. 3, p. 205.

No. 34. Cord. G. C. 22838.

4693
—

Extremely faint band. No photograph taken. Its altitude on the meridian is only 8°.

No. 35. Cord. G. C. 22843.

| H$\beta$ | |
|---|---|
| 4863 | 4686.7 |
| ..... | 4687.2 |
| (4863) | 4687 |
| — | — |

Photographic: 4688, 4637. The H$\gamma$ line is dark, with bright border, on red side, possibly double-reversed.

The difficult line measured visually at (4863) is possibly a similar bright border on the red side of H$\beta$.

No. 36. Cord. G. C. 23072.

No bright lines observable.

Photographic: The H$\gamma$ line is dark. There is a possible trace of bright 469, but it is very doubtful. Is this star of the Wolf-Rayet type?

No. 37. Cord G. C. 23073.

4689.5
4690.2
4690
—

Photographic: 4688, 4637. H$\gamma$ is dark.

No. 38. Cord. G. C. 23416.

| | | | | | | | | | | H$\beta$ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5814.4 | 5690.9 | 5590.4 | 5471 | 5413 | 5286 | 5252 | 5133 | 5017.1 | 4936 | 4862 | 4785 | 4691.7 | 4652.2 | 454 |
| 5812.8 | 5693.8 | 5592.7 | ..... | ..... | ..... | ..... | ..... | 5019.8 | 4940 | ..... | ..... | 4692.7 | 4651.4 | .... |
| ..... | ..... | 5590.9 | ..... | ..... | ..... | ..... | ..... | 5021.6 | ..... | ..... | ..... | ..... | ..... | .... |
| 5813 | 5692 | 5591 | 5471 | 5413 | 5286 | 5252 | 5133 | 5019 | 4938 | 4862 | 4785 | 4692 | 4652 | 454 |
| ++ | + | + | + | + | — | | | | — | + | + | | ++ | — |

Photographic: 4688, 4651, 4544, 449, 4444, 432.
+ ++

H$\gamma$ is probably bright; but if so, it is shifted to the violet considerably. 4444 is very broad and possibly double. The band 469

is very faint visually. The greatest altitude of this star is about 7°.

No. 39. Cord. Z. C. 17$^h$ 3612.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5816.0 | 5695.5 | 5591.1 | 5474 | 5410.8 | 5249 | 5132 | 5021.8 | 4939 | 4862 | 4789 | 4691.0 | 4653.7 |
| 5815.5 | 5695.4 | 5589.4 | ..... | ..... | ..... | ..... | 5021.8 | 4935 | ..... | ..... | 4691.1 | 4653.2 |
| 5818.5 | 5692.9 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 5817 | 5694 | 5590 | 5474 | 5411 | 5249 | 5132 | 5022 | 4937 | 4862 | 4789 | 4691 | 4653 |
| | ++ | − | − | | − | | | − | | − | | ++ |

No photograph taken.

No. 40. SDM. — 19° 4854.

| | Hβ | | |
|---|---|---|---|
| 5413 | 4862 | 4686 | 454 |
| | − | ++ | − |

No photograph taken.

No. 41. SDM. — 21° 4864.

| | | | | | | | | | | Hβ | | | | Hγ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5814.8 | 5692.6 | 5596.1 | 5471.0 | 5410.5 | 5282.0 | 5241.0 | 5121.0 | 5023.0 | 4940.4 | 4861.1 | 4789.0 | 4655 | 4543 | 4443 | 4338 |
| 5810.6 | 5691.8 | 5591.0 | 5470.1 | 5412.5 | 5282.4 | 5248.6 | 5124.8 | 5022.5 | 4939.1 | ..... | 4786.5 | 4649 | 4540 | 4442 | ..... |
| 5813.6 | 5690.6 | 5592.9 | 5473.1 | 5409.9 | 5280.0 | 5249.2 | 5123.0 | 5022.0 | 4937 4 | ..... | 4785.5 | 4658 | 4535 | 4440 | ..... |
| ..... | ..... | 5594.4 | ..... | ..... | 5282.4 | ..... | 5122.7 | 5023.2 | .. .. | ..... | ..... | ..... | ..... | ..... | ..... |
| 5813 | 5692 | 5594 | 5471 | 5411 | 5284 | 5246 | 5123 | 5023 | 4939 | 4861 | 4786 | 4653 | 4541 | 4442 | 4338 |
| + + | + | + | + | + | | | | | | + | | + + | | | |

Photographic: 469, 465, 454, 4493, 4442, 4389, 4369, 4341.
+ + + + + + +

The band at 4442 is very wide and possibly double. The bands at 469 and 465 are unusually wide and overlap considerably.

The visual intensity curve for this spectrum is given on Fig. 2; and the photographic intensity curve on Fig. 3.

Pickering, at Cambridge in 1881, observed bright lines at 582, 470.—*Nature*, Vol. 23, p. 604.

Vogel, at Potsdam in 1881-2, observed a bright line at 5824, and the middle of a broad bright line at 4655. At Vienna, in 1883, he observed a bright line at 581, and the brightest place in a bright broad line at 466.—*Publ. Potsdam*, Vol. 4, p. 16.

No. 42. SDM.—11° 4593.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5813.5 | 5696.3 | 5590 | 5471 | 5410 | 5251 | 5132 | 5019.7 | 4942.7 | 4652.2 |
| ..... | ..... | ..... | ..... | ..... | ..... | ..... | 5022.5 | ..... | ..... |
| 5816.2 | 5694.3 | ..... | ..... | ..... | ..... | ..... | 5022.3 | 4944.0 | 4654.0 |
| 5815 | 5695 | 5590 | 5471 | 5410 | 5251 | 5132 | 5022 | 4943 | 4653 |
| + | ++ | − | − | − | − | − | − | − | ++ |

Photographic: 4687, 4650, 4480, 4442.
+ ++ +

The band at 469, shown on the photograph, is not observable visually.

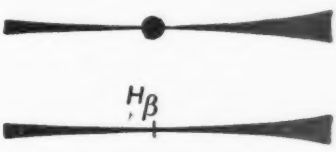
## No. 43. DM. + 30° 3639.

| Hα | $D_3$ | | | | | | | | | | Hβ | | | | | | Hγ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6563 | 588 | 581 | 5691.5 | 559 | 5412.2 | 529 | 5252 | 5131.3 | 5022 | 4941 | 4861.1 | 4786 | 4691.4 | 4651.5 | 4444 | 4340.3 |
| ..... | .... | .... | 5693.6 | .... | 5410.1 | .... | 5263 | 5138.5 | 5017 | 4938 | 4861.9 | 4787 | 4689.4 | 4252.8 | ..... | ..... |
| ..... | .... | .... | 5693.4 | .... | ..... | .... | 5244 | 5141.0 | 5020 | ..... | ..... | 4786 | 4687.6 | 4653.1 | ..... | ..... |
| ..... | .... | .... | 5695.9 | .... | ..... | .... | 5260 | 5130.0 | 5021 | ..... | ..... | ..... | ..... | 4652.6 | ..... | ..... |
| ..... | .... | .... | 5694.7 | .... | ..... | .... | 5258 | 5133.3 | ..... | ..... | ..... | ..... | ..... | 4649.3 | ..... | ..... |
| ..... | .... | .... | 5694.3 | .... | ..... | .... | 5249 | 5137.7 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| ..... | .... | .... | 5693.0 | .... | ..... | .... | ..... | 5130.7 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| ..... | .... | .... | 5695.0 | .... | ..... | .... | ..... | 5133.3 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| ..... | .... | .... | 5695.3 | .... | ..... | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| ..... | .... | .... | 5693.9 | .... | ..... | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| ..... | .... | .... | 5693.5 | .... | ..... | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 6563 | 588 | 581 | 5694.0 | 559 | 5411 | 529 | 5255 | 5135 | 5020 | 4939 | 4861.5 | 4786 | 4689 | 4652 | 4444 | 4340 |
| — | | | ++ | | — | | | | | — | ++ | | | + | — | + |

Photographic: 4862, 4689, 4653, 4621, 4592, 4555, 4544, 4517, 4474, 4457
++ + ++ + + +

4444, 4416, 4389, 4369, 4341, 4323, 4267.
+ + ++

The lines in this spectrum are better defined than those in any of the other spectra. The brightest lines are the hydrogen lines Hβ and Hγ. They are true monochromatic images of the slit, and the second measure of the Hβ line was made with a second order grating. The line at λ 5694 is well defined, and indeed appears to be monochromatic. I have for that reason determined its wave-length a large number of times. Several of the lines have not been found in any of the other stars; and in many respects, as Mrs. Fleming pointed out* at the time of discovery, its appearance differs from that of the other stars of this class.




I have observed this star to be surrounded by an incandescent hydrogen envelope. This observation was made spectroscopically, and presented no difficulties. The principal features of this spectrum, aside from the continuous spectrum, consist of the bright line at λ 5694, the bright band at λ 4652 and the very bright Hβ line. When the spectroscope was adjusted for the various parts of the spectrum the line at λ 5694 appeared essentially as a stellar point; the band at λ 4652 was broad but short and lay wholly upon the continuous spectrum; but the hydrogen line Hβ *was narrow and long, extending a very appreciable distance each side of the continuous spectrum.* When the slit was

* *Astronomische Nachrichten*, No. 2986.

opened wide the H$\beta$ line became *a circular disc*, while the line $\lambda$ 5694 and the band $\lambda$ 4652 remained unchanged. The appearances of the H$\beta$ line with open slit and with narrow slit are shown in the accompanying cut. The diameter of the disc was measured with the micrometer and found to be about 5″. The H$\gamma$ line and the very faint H$\alpha$ line were seen, with open slit, to have similar forms. There can be no doubt that the observed appearances are due to an envelope of incandescent hydrogen surrounding the nucleus which yields the continuous spectrum and the other bright lines. The large size of the envelope may be due in part to the nearness of this star to the solar system; but as to that, no statement can now be made.

The other stars of this type were examined for discs, spectroscopically, but none were discovered.

The superiority of the spectroscopic method for observations of this kind is at once evident. Indeed, the above observation could not be made with the 36-inch refractor, using an ordinary eyepiece. While it was seen that the light in this star is unusually distributed, the effects of the large chromatic aberration could not be eliminated sufficiently to permit the detection of the disc.

A photographic intensity curve of this spectrum is given on Fig. 3.

No. 44. DM. + 35°3953.

4684.5
4689 5
4687.9
4687.4

4687
+

Photographic: 469. H$\gamma$ dark. Traces of dark lines at 4473, 4416, 4389, 432.

No. 45. DM. + 35°4001.

| $D_3$ | | | | | | H$\beta$ | | | | | H$\gamma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5877.6 | 581 | 5413.2 | 5134.5 | 5021.7 | 4939.3 | 4861.9 | 4791 | 4684.2 | 4614 | 4541 | 4341 |
| ..... | ..... | 5410.4 | 5135.2 | 5022.9 | 4939.2 | ..... | 4787 | 4685.4 | 4622 | 4535 | ..... |
| ..... | ..... | 5413.0 | ..... | ..... | 4938.6 | ..... | 4786 | 4685.9 | 4617 | ..... | ..... |
| ..... | ..... | 5412.9 | ..... | ..... | ..... | ..... | ..... | 4688.3 | 4612 | ..... | ..... |
| ..... | ..... | 5411.8 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 5878 | 581 | 5412 | 5135 | 5022 | 4939 | 4862 | 4788 | 4686 | 4616 | 4538 | 4341 |
| − | | ++ | − | − | | + | − | ++ | + | | |

Photographic: 4862, 4787, 4687, 4650, 4627, 4598, 4541, 4508, 4481, 4465, 4442,
++ + +

4369, 4341, 420, 4102, 406.
+ + +

The band observed visually at 4616 is shown by the photograph to consist of two, at 4627 and 4598. This spectrum is almost identical with that of DM. + 37° 3821. [See Fig. 2].

Wolf and Rayet observed bright lines in this star in 1867, but did not identify them.—*Comptes Rendus*, Vol. 65, p. 292.

Vogel, at Vienna in 1883, constructed a visual intensity curve for this spectrum, and observed the following bright lines: 583, very faint; 571, very faint, only suspected; 541, bright line; 486, fairly bright (H$\beta$); 486, brightest place in bright band.—*Publ. Potsdam*, Vol. 4, pp. 18, 21.

Copeland, using the 15-inch Dun Echt refractor, observed a bright line at 5412, a faint line at 5220, and a large blue band at 4695.—*Proc. Roy. Soc.*, Vol. 49, p. 43.

Pickering states that the Draper spectrum photographs show a blue band at 469, and bright lines at 462, 455, 434, 420, 410, 406, 402, 397, 395, 389, 388.—*Proc. Roy. Soc.*; Vol, 49, p. 36.

Dr. and Mrs. Huggins' intensity curve of the band near 469 places the maximum brightness at about 4687.—*Proc. Roy. Soc.*, Vol. 49, p. 34.

No. 46. DM. + 35° 4013.

| | | | | | | | | H$\beta$ | | | | | | H$\gamma$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5881.6 | 5813.8 | 5691.5 | 5590.8 | 5468.3 | 5412.4 | 5130 | 5022 | 4934 | 4862 | 4785 | 4690.4 | 4652.1 | 4546 | 4440 | 4340 |
| 5876.7 | 5812.3 | 5693.5 | 5594.2 | 5469.2 | 5411.7 | 5127 | 5015 | 4939 | ..... | 4787 | 4689.5 | 4650.7 | 4540 | 4438 | ..... |
| 5875.6 | 5812.8 | 5695.4 | 5593.8 | 5468.4 | 5412.0 | 5132 | 5020 | 4937 | ..... | 4786 | 4689.7 | 4652.5 | ..... | ..... | ..... |
| 5873.7 | ..... | ..... | ..... | 5469.8 | 5412.5 | 5133 | 5019 | ..... | ..... | ..... | 4688.0 | 4652.9 | ..... | ..... | ..... |
| ..... | ..... | ..... | ..... | 5469.5 | 5410.4 | ..... | ..... | ..... | ..... | ..... | 4690.4 | 4652.0 | ..... | ..... | ..... |
| ..... | ..... | ..... | ..... | 5468.0 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 5877 | 5813 | 5693 | 5593 | 5469 | 5412 | 5130 | 5019 | 4937 | 4862 | 4786 | 4690 | 4652 | 4543 | 4439 | 4340 |
| | ++ | ++ | | + | + | | | − | | | | ++ | | + | |

Photographic: 4862, 4788, 4688, 4652, 4543, 4518, 4504, 4480, 4465, 4441,
+ + ++ ++ + + + + ++

4343, 4334, 4316, 4277, 4260, 4227, 420, 4102, 4064, 4023.
+ + + + + + + +

The line at 4510 is pretty certainly double, with components at 4518 and 4504. The lines at 4480 and 4465 may possibly be the very bright borders of a doubly reversed line at 4473, but that is hardly probable. All the lines in this star are really bands of different widths, except possibly those at 4343 and 4334, near H$\gamma$. The appearance at H$\gamma$ is very peculiar; neither of the fine bright lines coincides with the artificial hydrogen line, nor is there any basis for classing it as a double reversal.

The visual intensity curve of this star is given on Fig. 2; and the photographic curve on Fig. 3.

Wolf and Rayet observed four bright lines in this star, and made micrometer readings upon them. Their lines are probably those at 581, 569, 541, 465.—*Comptes Rendus*, Vol. 65, p. 292.

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Vogel, at Vienna in 1883, observed very bright lines at 582, 570, and the brightest place in a broad weak band at 464. He also constructed a visual intensity curve.—*Publ. Potsdam*, Vol. 4, pp. 19, 21.

Copeland, at Dun Echt in 1884, observed bright lines at 5824, 5689, 5410 and a large band at 4654.—*Proc. Roy. Soc.*, Vol. 49, p. 43.

Dr. and Mrs. Huggins in 1890 observed a bright band whose maximum brightness is near 4650, and a faint band with maximum near 4690. They likewise observed a group of bright lines at about $\lambda$ 5690 and a faint line near $D_3$.—*Proc. Roy. Soc.*, Vol. 49, pp. 34, 44.

No. 47. D.M. + 37° 3821.

| Hα | $D_3$ | | | | | | Hβ | | | | Hγ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6562.8 | 5876.6 | 581 | 569 | 5411.8 | 5022.3 | 4942.3 | 4861.3 | 4786.0 | 4685.2 | 4628.9 | 4539.6 | 4341 |
| ..... | ..... | ..... | ..... | 5411.5 | 5022.3 | 4940.9 | 4862.1 | 4785.7 | 4685.3 | 4627.8 | 4541.3 | ..... |
| ..... | ..... | ..... | ..... | 5410.5 | ..... | 4938.4 | ..... | ..... | 4686.8 | 4628.4 | 4541.1 | ..... |
| ..... | ..... | ..... | ..... | 5410.7 | ..... | ..... | ..... | ..... | 4687.2 | 4630.8 | ..... | ..... |
| ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 4686.4 | 4629.7 | ..... | ..... |
| ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 4631.2 | ..... | ..... |
| 6563 | 5877 | 581 | 569 | 5411 | 5022 | 4941 | 4862 | 4786 | 4686 | 4629 | 4541 | 4341 |
| | | | | + | + | | + | − | ++ | + | | |

Photographic: 4862 4787 4687 4650 4627 4598 4541 4508 4481 4465 4442
++ + + ++ +

4341 420 4102 4062
++ + +

All these lines are broad except possibly 4598. There is an absorption line at about 4457. The bright Hα line is easily visible. This spectrum is almost identical with that of D.M. + 35° 4001.

The visual intensity curve for this star is given on Fig. 2; and the photographic curve on Fig. 3.

Dr. and Mrs. Huggins, in 1890, placed the maximum of the blue band at about 4690. They also observed the Hβ line to be very bright.—*Proc. Roy. Soc.*, Vol. 49, pp. 34, 45.

No. 48. DM. + 36° 3956.

| $D_3$ | | | | | | | | | Hβ | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5875.2 | 5815.9 | 5693.6 | 5599.7 | 5472.2 | 5412.3 | 5135 | 5019 | 4941 | 4862 | 4785 | 4690.1 | 4652.3 | 454 | 444 |
| ..... | 5812.3 | 5693.5 | 5596.8 | 5472.0 | 5410.8 | 5130 | 5021 | 4939 | ..... | 4786 | 4689.3 | 4650.9 | .... | .... |
| ..... | 5812.5 | 5692.5 | 5591.9 | 5472.2 | 5412.2 | ..... | ..... | ..... | ..... | ..... | 4691.7 | 4654.1 | .... | .... |
| ..... | 5809.7 | 5693.5 | ..... | 5472.4 | ..... | ..... | ..... | ..... | ..... | ..... | 4692.7 | 4651.3 | .... | .... |
| ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 4652.5 | .... | .... |
| ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 4652.6 | .... | .... |
| 5875 | 5813 | 5693 | 5596 | 5472 | 5412 | 5132 | 5020 | 4940 | 4862 | 4785 | 4691 | 4652 | 454 | 444 |
| | ++ | + | | + | | − | − | | − | | | ++ | | |

Photographic: 4790, 4690, 4651, 4540, 4510, 4442, 4340, 4314, 4277, 4260, 4229.
+ ++ ++

This spectrum strongly resembles that of DM. + 35° 4013.

Wolf and Rayet observed bright lines in this star in 1867, but give no wave-lengths.—*Comptes Rendus*, Vol. 65, p. 292.

Vogel, at Vienna in 1883, observed bright lines 582, 569, and the brightest place of a band at 464. He constructed a visual intensity curve also.—*Publ. Potsdam*, Vol. 4, pp. 20, 21.

Copeland, at Dun Echt in 1884, observed bright lines at 5810. 5704, a faint line at 5233, and a large blue band at 4649.—*Proc, Roy Soc.*, Vol. 49, p. 43.

Dr. and Mrs. Huggins, in 1890, observed the maximum of the bright blue band to be at about 4650, and a faint band at about 4688.—*Proc. Roy. Soc.*, Vol. 49, p. 34.

No. 49. DM. + 36° 3987.

| | Hβ | | | | |
|---|---|---|---|---|---|
| 5414.8 | 4862 | 4786 | 4684.8 | 4633 | 454 |
| 5411.8 | ..... | ..... | 4687.6 | 4635 | ..... |
| ..... | ..... | ..... | 4686.1 | ..... | ..... |
| ..... | ..... | ..... | 4686.6 | ..... | ..... |
| ..... | ..... | ..... | 4685.4 | ..... | ..... |
| 5413 | 4862 | 4786 | 4686 | 4634 | 454 |
| | | − | + | − | |

Photographic: 4688, 4636, 4615, 454, 4341.
++

No. 50. DM. + 38° 4010.

| | | | | | | |
|---|---|---|---|---|---|---|
| 581 | 569 | 5411.6 | 4854 | 4689.2 | 4631 | 454 |
| ..... | ..... | 5410.7 | 4856 | 4682.9 | 4636 | ..... |
| ..... | ..... | 5414.3 | ..... | 4686.5 | ..... | ..... |
| 581 | 569 | 5412 | 4855 | 4686 | 4633 | 454 |
| | | | | ++ | − | |

Photographic: 4689, 4637, 454.
++

Hγ is dark with edges slightly bright. It is probably a doubly reversal.

The line observed visually at 4855 was seen to be more refrangible than the hydrogen artificial Hβ, and my notes say "Probably Hβ not present." It may be the bright margin of a doubly reversed Hβ.

No. 51. DM. + 43° 3571.

| Hα | | | | | | Wide Band. | |
|---|---|---|---|---|---|---|---|
| 6564.7 | 5850 | 5806 | 569 | 559 | 5135 | 4712 — 4610 | |
| ..... | 5848 | 5801 | ..... | ..... | 5135 | 4719 — 4612 | |
| ..... | 5846 | 5806 | ..... | ..... | ..... | 4710 — 4610 | |
| ..... | 5849 | 5803 | ..... | ..... | ..... | ..... | ..... |
| 6565 | 5848 | 5804 | 569 | 559 | 5135 | 4714 — 4611 | |
| − | + | ++ | | | − | + | + |

Photographic: 469, 465.
+ ++

The H$\beta$, H$\gamma$, and H$\delta$ lines are dark, with slightly brightened broad borders: they are probably double-reversed. The bands at 469 and 465 are broader than in any of the other stars observed. The brighter one, 465, overlaps 469 and is itself about 80 tenth-meters broad and nearly uniform throughout. The line observed as H$\alpha$ is very faint, rather broad, and may be the bright borders of a dark H$\alpha$. It may be, however, that H$\alpha$ is bright and the other hydrogen lines are dark, as in $\gamma$ Argus.

The lines in this star are all very broad. Some are also unsymmetrical, and these wave-lengths should have little weight when the results for all the stars are combined.

No. 52. DM. + 36° 4028.

| | | | | H$\beta$ | | | |
|---|---|---|---|---|---|---|---|
| 581 | 569 | 5412.7 | 4938 | 4861.5 | 4684.5 | 463 | 454 |
| ..... | ..... | 5413.0 | ..... | 4861.2 | 4688.9 | ..... | ..... |
| ..... | ..... | 5411.5 | ..... | ..... | 4686.4 | ..... | ..... |
| ..... | ..... | ..... | ..... | ..... | 4685.6 | ..... | ..... |
| 581 | 569 | 5412 | 4938 | 4861 | 4686 | 463 | 544 |
| | | | − | | ++ | | |

Photographic: 4686, 465, 4627, 460, 454
++

No. 53. DM. + 55° 2721.

| $D_3$ | | | H$\beta$ | | | |
|---|---|---|---|---|---|---|
| 5879 | 581 | 5413 | 4860 | 4689.6 | 4630 | 454 |
| ..... | ..... | ..... | ..... | 4689.2 | ..... | ..... |
| ..... | ..... | ..... | ..... | 4685.8 | 4633 | ..... |
| ..... | ..... | ..... | ..... | 4688.4 | ..... | ..... |
| 5879 | 581 | 5413 | 4860 | 4688 | 4631 | 454 |
| − | | − | | ++ | − | |

Photographic: 4688, 4635, 454.
++

No. 54. Anonymous.

| | | | | | | | Broad Band. | Maximum. |
|---|---|---|---|---|---|---|---|---|
| 5812.2 | 569 | 559 | 5472 | 5413 | 5019 | 4865 | 4704 to 4617 | 4651 |
| 5811.0 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 4650 |
| 5809.6 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 4653 |
| 5811 | 569 | 559 | 5472 | 5413 | 5019 | 4865 | 4704 to 4617 | 4651 |
| + | | | − | − | − | − | | ++ |

No photograph taken. The two bands at 469 and 465 overlap considerably, as in SDM. − 21° 4864, that at 465 being the brighter.

No. 55. DM + 56°.2818.

| | Hβ | | | |
|---|---|---|---|---|
| 5414.5 | 4862 | 4686.4 | 463 | 454 |
| 5412.5 | ..... | 4689.3 | ..... | ..... |
| ..... | ..... | 4688.2 | ..... | ..... |
| ..... | ..... | 4685.6 | ..... | ..... |
| ..... | ..... | 4687.7 | ..... | ..... |
| 5413 | 4862 | 4687 | 463 | 454 |
| | − | ++ | | |

Photographic: 4688, 4637, 454.
++ +

The wave-lengths of the bright bands observed visually in these stars are brought together in Table II, and those observed photographically (including a few dark lines) in Table III. The means for the several lines have been formed with due regard to the character and relative number of observations of the lines in the different stars. In Table III the dark lines with brightened borders are marked "rev.," signifying possible double reversal.

I wish to emphasize the fact that the lines in these spectra have a great variety of forms and intensities. The hydrogen lines are especially noteworthy: they have nearly every known character. In many of the stars they are dark. Again, they are dark with bright borders, and suggest strongly that they are doubly reversed. The bright hydrogen lines vary from faint to very bright, from monochromatic lines to very broad bands, and from those clearly single to those apparently multiple. The other prominent bright bands are of very different widths and intensities in the different stars. Many of the bands are always faint, as will be seen from the symbols written below their wave-lengths. These symbols and the notes given with the tables of measures for each star make further descriptions unnecessary here.

It will be noticed in Table III that several of the lines do not appear in many stars. That is due, in some measure, to the different degrees of exposure of the various plates; and further to the fact that the star + 30° 3639 appears to be of a somewhat different type from the others. Many apparent lines have been omitted because a second plate has not yet been taken to test their reality.

The photographs show, even better than the visual observations, that the blue bands at 4688 and 4652 are often associated in the same spectrum. The band at 4636 is distinctly separate from those at 4652 and 4626, and is found in several stars.

XUM

| No. | Star. | Hα | $D_3$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | DM. + 63°83 | | | | 581 | | | | 5413 | | | | 5023 |
| 2 | " + 56°686 | | | | 5814 | 5691 | 5594 | 5472 | 5412 | 526 | 5124 | 5020 |
| 3 | " + 56°731 | | | | 5812 | 5691 | 5594 | 5470 | 5411 | | | |
| 4 | Cord. G. C. 8631 | 6563 | 588 | | 5807 | 569 | 559 | 5471 | 5416 | | | |
| 5 | γ Argus | 6565 | 5874 | | 5813 | 5694 | 5596 | 5470 | 5411 | | 5135 | 5020 |
| 6 | Cord. Z. C. $8^h$4141 | | | | 5813 | 5690 | 559 | | 542 | | | |
| 30 | " " $15^h$4129 | | | | | | | | | | 5133 | |
| 31 | " G. C. 22748 | | | | | | | | | | | |
| 32 | " " 22763 | | | | | | | 5473 | 5412 | | 5133 | 5022 |
| 33 | " " 22827 | | 588 | | 5812 | 5693 | 559 | 5474 | 5414 | | | |
| 34 | " " 22838 | | | | | | | | | | | |
| 35 | " " 28843 | | | | | | | | | | | |
| 37 | " " 23073 | | | | | | | | | | | |
| 38 | " " 23416 | | | | 5813 | 5692 | 5591 | 5471 | 5413 | 5286 | 5252 | 5133 | 5019 |
| 39 | " Z. C. $17^h$3612 | | | | 5817 | 5694 | 5590 | 5474 | 5411 | | 5249 | 5132 | 5022 |
| 40 | SDM. − 19°4854 | | | | | | | | 5413 | | | | |
| 41 | " − 21°4864 | | | | 5813 | 5692 | 5594 | 5471 | 5411 | 5284 | 5246 | 5123 | 5023 |
| 42 | " − 11°4593 | | | | 5815 | 5695 | 5590 | 5471 | 5410 | | 5251 | 5132 | 5022 |
| 43 | DM. + 30°3639 | 6563 | 588 | | 581 | 5694 | 559 | | 5411 | 529 | 5255 | 5135 | 5020 |
| 44 | " + 35°3953 | | | | | | | | | | | | |
| 45 | " + 35°4001 | | 5878 | | 581 | | | | 5412 | | | 5135 | 5022 |
| 46 | " + 35°4013 | | 5877 | | 5813 | 5693 | 5593 | 5469 | 5412 | | | 5130 | 5019 |
| 47 | " + 37°3821 | 6563 | 5877 | | 581 | 569 | | | 5411 | | | | 5022 |
| 48 | " + 36°3956 | | 5875 | | 5813 | 5693 | 5596 | 5472 | 5412 | | | 5132 | 5020 |
| 49 | " + 36°3987 | | | | | | | | 5413 | | | | |
| 50 | " + 38°4010 | | | | 581 | 569 | | | 5412 | | | | |
| 51 | " + 43°3571 | 6565 | | 5848 | 5804 | 569 | 559 | | | | | 5135 | |
| 52 | " + 36°4028 | | | | 581 | 569 | | | 5412 | | | | |
| 53 | " + 55°2721 | | 5879 | | 581 | | | | 5413 | | | | |
| 54 | Anonymous | | | | 5811 | 569 | 559 | 5472 | 5413 | | | | 5019 |
| 55 | DM. + 56°2818 | | | | | | | | 5413 | | | | |
| | Means | 6564 | 5877 | 5848 | 5813 | 5693 | 5593 | 5472 | 5412 | 5284 | 5250 | 51 31 | 5021 |

| No. | | Hβ | | | | | | | | Hγ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4938 | 4861 | | 4687 | | | 4615 | 454 | | |
| | − | − | | ++ | | | − | − | | |
| 2 | | 4861 | 4787 | 469 | 4653 | | | 4534 | | |
| | | − | − | | ++ | | | − | | |
| 3 | | | | 469 | 4654 | | | 454 | | |
| | | | | | ++ | | | | | |
| 4 | 4943 | 4862 | 4789 | 4688 | | | 4614 | 4544 | | 4342 |
| | | + | | ++ | | | + | + | | |
| 5 | 494 | | 4787 | 4689 | 4651 | | | | 4441 | |
| | | | | + | ++ | | | | + | |
| 6 | | 4862 | | 4690 | 4651 | | | 454 | | |
| | | | | | ++ | | | | | |
| 30 | 4942 | | | 4687 | | | | | | |
| | − | | | | | | | | | |
| 31 | | | | 4690 | | | | | | |
| | | | | − | | | | | | |
| 32 | 4941 | 4861 | 4785 | 4687 | | 4638 | | | | |
| | − | + | − | ++ | | ++ | | | | |
| 33 | | (4863) | 4785 | 469 | 4653 | | | | | |
| | | − | − | | ++ | | | | | |
| 34 | | | | 4693 | | | | | | |
| | | | | − | | | | | | |
| 35 | | (4863) | | 4687 | | | | | | |
| | | − | | − | | | | | | |
| 37 | | | | 4690 | | | | | | |
| | | | | − | | | | | | |
| 38 | 4938 | 4862 | 4785 | 4692 | 4652 | | | 454 | | |
| | − | + | + | | ++ | | | − | | |
| 39 | 4937 | 4862 | 4789 | 4691 | 4653 | | | | | |
| | − | | − | | ++ | | | | | |
| 40 | | 4862 | | 4686 | | | | 454 | | |
| | | − | | ++ | | | | − | | |
| 41 | 4939 | 4861 | 4786 | 469 | 4653 | | | 4541 | 4442 | 4338 |
| | | + | | | ++ | | | | | |
| 42 | 4943 | | | | 4653 | | | | | |
| | − | | | | ++ | | | | | |
| 43 | 4939 | 4862 | 4786 | 4689 | 4652 | | | | 4444 | 4340 |
| | − | ++ | | | + | | | | − | + |
| 44 | | | | 4687 | | | | | | |
| | | | | + | | | | | | |
| 45 | 4939 | 4862 | 4788 | 4686 | | | 4616 | 4538 | | 4341 |
| | | + | − | ++ | | | + | | | |
| 46 | 4937 | 4862 | 4786 | 4690 | 4652 | | | 4543 | 4439 | 4340 |
| | − | | | | ++ | | | | + | |
| 47 | 4941 | 4862 | 4786 | 4686 | | 4629 | | 4541 | | 4341 |
| | | + | − | ++ | | + | | | | |
| 48 | 4940 | 4862 | 4785 | 4691 | 4652 | | | 454 | 444 | |
| | | − | | | ++ | | | | | |
| 49 | | 4862 | 4786 | 4686 | | 4634 | | 454 | | |
| | | | − | | | − | | | | |
| 50 | | (4855) | | 4686 | | 4633 | | 454 | | |
| | | | | ++ | | − | | | | |
| 51 | | | | {4714 | broad | band | 4611 | | | |
| | | | | { + | ++ | | } | | | |
| 52 | 4938 | 4861 | | 4686 | | 463 | | 454 | | |
| | − | | | ++ | | | | | | |
| 53 | | 4860 | | 4688 | | 4631 | | 454 | | |
| | | | | ++ | | − | | | | |
| 54 | | 4865 | | {469 | 4651 | broad | band | | | |
| | | − | | { | ++ | | } | | | |
| 55 | | 4862 | | 4687 | | 463 | | 454 | | |
| | | − | | ++ | | | | | | |
| | 4940 | 4862 | 4786 | 4688 | 4652 | 4633 | 4615 | 4540 | 4441 | 4340 |

TABLE III.—BRIGHT BANDS OBSERVED PHOTOGRAPHICALLY

| No. | Star. | Hβ | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | DM. + 63°83 | | | 4688 | | | | 4615 | | | 454 | | | | |
| | | | | ++ | | | | + | | | | | | | |
| 4 | Cord. G. C. 8631 | | | 4688 | | | 4628 | | 460 | | 454 | 451 | | | |
| | | | | ++ | | | + | | | | + | | | | |
| 5 | γ Argus. | | 4787 | 4688 | 4651 | | | | | | | 4517 | 4504 | | 4480 |
| | | | | + | ++ | | | | | | | | | | + |
| 31 | Cord. G. C. 22748 | | | 4689 | | 4637 | | | | | dark | dark | | | |
| | | | | + | | + | | | | | | | | | |
| 32 | " " 22763 | | | 4690 | | 4638 | | | | | 4543 | 4515 | | | |
| | | | | + | | + | | | | | | | | | |
| 33 | " " 22827 | | | 469 | 4652 | | | | | | | | | | |
| | | | | + | ++ | | | | | | | | | | |
| 35 | " " 22843 | | | 4688 | | 4637 | | | | | | | | | |
| 36 | " " 23072 | | | | | | | | | | | | | | |
| 37 | " " 23073 | | | 4688 | | 4637 | | | | | | | | | |
| 38 | " " 23416 | | | 4688 | 4651 | | | | | | 4544 | | | 449 | |
| | | | | + | ++ | | | | | | | | | | |
| 41 | SDM. — 21°4864 | | | 469 | 465 | | | | | | 454 | | | 4493 | |
| | | | | + | ++ | | | | | | + | | | + | |
| 42 | " — 11°4593 | | | 4687 | 4650 | | | | | | | | | | 4480 |
| | | | | + | ++ | | | | | | | | | | |
| 43 | DM. + 30°3639 | 4862 | | 4689 | 4653 | | 4621 | | 4592 | 4555 | 4544 | 4517 | | | |
| | | ++ | | + | ++ | | | | | | | + | | | |
| 44 | " + 35°3953 | | | 469 | | | | | | | | | | | |
| 45 | " + 35°4001 | 4862 | 4787 | 4687 | 4650 | | 4627 | | 4598 | | 4541 | 4508 | | | 4481 |
| | | | | ++ | | | + | | | | + | | | | |
| 46 | " + 35°4013 | 4862 | 4788 | 4688 | 4652 | | | | | | 4543 | 4518 | 4504 | | 4480 |
| | | | + | + | ++ | | | | | | ++ | + | + | | + |
| 47 | " + 37°3821 | 4862 | 4787 | 4687 | 4650 | | 4627 | | 4598 | | 4541 | 4508 | | | 4481 |
| | | | | ++ | | | + | | + | | ++ | + | | | |
| 48 | " + 36°3956 | | 4790 | 4690 | 4651 | | | | | | 4540 | 4510 | | | |
| | | | | + | ++ | | | | | | | | | | |
| 49 | " + 36°3987 | | | 4688 | | 4635 | | 4615 | | | 454 | | | | |
| | | | | ++ | | | | | | | | | | | |
| 50 | " + 38°4010 | | | 4689 | | 4637 | | | | | 454 | | | | |
| | | | | ++ | | | | | | | | | | | |
| 51 | " + 43°3571 | dark rev. | | 469 | 465 | | | | | | | | | | |
| | | | | + | ++ | | | | | | | | | | |
| 52 | " + 36°4028 | | | 4686 | 465 | | 4627 | | 460 | | 454 | | | | |
| | | | | ++ | | | | | | | | | | | |
| 53 | " + 55°2721 | | | 4688 | | 4635 | | | | | 454 | | | | |
| | | | | ++ | | | | | | | | | | | |
| 55 | " + 56°2818 | | | 4688 | | 4637 | | | | | 454 | | | | |
| | | | | ++ | | + | | | | | | | | | |
| | Means | 4862 | 4787 | 4688 | 4651 | 4636 | 4626 | 4615 | 4596 | 4555 | 4542 | 4517 | 4504 | 4493 | 4480 |

IN THE WOLF-RAYET STARS.

| No. | | | | | | | | Hγ | | | | | | | Hδ | | | Hε |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | 4341 ++ | | | | | | 420 ++ | 4102 + | | | |
| 5 | dark | 4467 + | | 4442 ++ | | | | dark | | 432 | 4270 | | 4227 | | dark | | | dark |
| 31 | dark | | | | | | | dark rev ? | | | | | | | | | | |
| 32 | 4473 | | | | | | | 4340 + | | | | | | | | | | |
| 33 | | | | | | | | dark rev. | | | | | | | | | | |
| 35 | | | | | | | | dark | | | | | | | | | | |
| 36 | | | | | | | | dark | | | | | | | | | | |
| 37 | | | | | | | | dark rev. | | | | | | | | | | |
| 38 | | | | 4444 | | | | | | 432 | | | | | | | | |
| 41 | | | | 4442 ++ | | 4389 | 4369 | 4341 + | | | | | | | | | | |
| 42 | | | | 4442 + | | | | | | | | | | | | | | |
| 43 | 4474 + | | 4457 + | 4444 + | 4416 + | 4389 | 4369 | 4341 ++ | | 4323 | 4267 | | | | | | | |
| 44 | dark | | | | dark | dark | | dark | | dark | | | | | | | | |
| 45 | | 4465 | | 4442 | | | 4369 | 4341 + | | | | | | 420 + | 4102 + | 406 | | |
| 46 | | 4465 + | | 4441 ++ | | | | 4343 + | 4334 + | 4316 + | 4277 + | 4260 + | 4227 + | 420 + | 4102 + | 4064 | 4023 | |
| 47 | | 4465 | | 4442 | | | 4369 | 4341 ++ | | | | | | 420 + | 4102 + | 4062 | | |
| 48 | | | | 4442 ++ | | | | 4340 | | 4314 | 4277 | 4260 | 4229 | | | | | |
| 49 | | | | | | | | 4341 | | | | | | | | | | |
| 50 | | | | | | | | dark | | | | | | | | | | |
| 51 | | | | | | | | dark rev. | | | | | | | dark rev. | | | |
| 52 | | | | | | | | | | | | | | | | | | |
| 53 | | | | | | | | | | | | | | | | | | |
| 55 | | | | | | | | | | | | | | | | | | |
| | 4473 | 4466 | 4457 | 4443 | 4416 | 4389 | 4369 | 4341 | 4334 | 4318 | 4273 | 4260 | 4228 | 420 | 4102 | 4063 | 4023 | |

Without going further into details, it is now a question of identifying the lines and bands with the lines of known elements, and of assigning to these stars their place along with other types of celestial objects. A most perplexing question!

The hydrogen lines H$\alpha$, H$\beta$, H$\gamma$, H$\delta$, are present, but the other lines do not admit of certain identification. Prominent iron and other lines may coincide with a few of the star lines, and the line at 4480 suggests a magnesium origin; but there are not enough points of identity with well-known artificial or stellar spectra to enable us to draw any safe conclusions.

The presence of bright lines in these stars suggests a comparison with other bright-line spectra. Professor Pickering has pointed out* that a probable close relation exists between them and the "Orion type" stars, four-fifths of which are in the Milky Way, and the planetary nebulæ, nearly all of which are in the Milky Way. It has also been suggested that the Wolf-Rayet stars are closely related to the "new stars." In order to facilitate the comparison of these and other spectra, I have constructed Table IV. The wave-lengths of the forty-five bright bands observed in the Wolf-Rayet stars are given in the first column. Opposite to them are placed possible corresponding bright lines in the solar chromosphere, Nova Aurigæ (February, 1892),† and the dark lines in the "Orion type" stars and $\beta$ Lyræ.

The hydrogen lines are prominent in all the six spectra. The $D_3$ and 4472 chromosphere lines appear, within the limits of error of the measures, to exist pretty prominently in all these types of spectra except that of Nova Aurigæ. $D_3$ was not observed at all in the latter spectrum, and 4473 was far from prominent (*schwer aufzufassen*).

If we omit the hydrogen, $D_3$ and 4472 lines, the remaining possible coincidences with solar chrmosphere lines are of extremely small weight. The chromosphere lines 5285 and 5019 are prominent, but they coincide with two of the faintest Wolf-Rayet lines. The other chromosphere lines are comparatively faint.

If we compare columns one and three we shall find that the coincidences are equally unsatisfactory. The prominent Wolf-Rayet lines are conspicuously absent from the spectrum of Nova Aurigæ, of Nova Normæ, and probably also of Nova Cygni; and the converse is likewise true. There are several possible coincidences, but on the whole they relate to faint lines in one or both of the spectra; and the great majority of the lines in the two

* *Astronomische Nachrichten*, No. 3025.

† Using the Potsdam and Lick lists of bright lines.

TABLE IV.—COMPARISON OF WOLF-RAYET AND OTHER SPECTRA.

| Wolf-Rayet Stars. | Solar Chromosphere. | Nova Aurigæ. | Gaseous Nebulæ. | Orion Stars Dark Lines | $\beta$ Lyræ Dark Lines. |
|---|---|---|---|---|---|
| 6564 | 6563 H$\alpha$ | 6563 | 6562 | | |
| 5877 | 5876 $D_3$ | | 5876 | 5876 | 5876 |
| 5848 | | | | | |
| 5813 | | | | | |
| 5693 | | | | | |
| 5593 | | | | | |
| 5472 | | | | | |
| 5412 | | | 5412 | | |
| 5284 | 5285 Fe | 5285 | | | |
| 5250 | | | | | |
| 5131 | | | | | |
| 5020 | 5019 Fe | 5016 | | 5021 | [5014] |
| 4940 | | | | | |
| 4862 | 4861 H$\beta$ | 4862 | 4861 | 4861 | 4861 |
| 4787 | | | | | |
| 4688 | | | 4687 | 4688 | |
| 4652 | | | | 4652 | 4652 |
| 4636 | | | | | |
| 4626 | [4630 Fe] | [4629] | | | 4630 |
| 4615 | | | | | |
| 4596 | | | | | |
| 4555 | 4556 Fe | 4556 | | | 4556 |
| 4541 | | | | 454 | 4544 |
| 4517 | | | | | |
| 4509 | | 4507 | | | 4510 |
| 4504 | | | | | |
| 4493 | 4490 Fe | 4490 | | | |
| 4480 | 4481 Mg | 4481 | | 4481 | 4481 |
| 4473 | 4472 | 4473 | 4472 | 4472 | 4471 |
| 4466 | | | | | |
| 4457 | | | | | |

| Wolf-Rayet Stars. | Solar Chromosphere. | Nova Aurigæ. | Gaseous Nebulæ. | Orion Stars. Dark Lines. | $\beta$ Lyræ Dark Lines. |
|---|---|---|---|---|---|
| 4442 | 4444 Fe | 4445 | | | |
| 4416 | | 4418 | | 4416 | |
| 4389 | | | 4389 | 4389 | 4388 |
| 4369 | | | | | |
| 4341 | 4341 H$\gamma$ | 4341 | 4341 | 4341 | 4340 |
| 4334 | | | | | |
| 4318 | | 4316 | | | |
| 4273 | | | | | |
| 4260 | | 4262 | | | |
| 4228 | | 4228 | 423 | 423 | |
| 420 | | | | 4203 | |
| 4102 | 4102 H$\delta$ | 4102 | 4102 | 4102 | 4102 |
| 4063 | | 4067 | 4067 | 4067 | 4062 |
| 4023 | | | 4026 | 4026 | 4026 |

spectra do not coincide with each other. Aside from the fact that the lines in the "new stars" and Wolf-Rayet stars are broad, these two types do not seem to have many points in common.

The second and third columns of the table are nearly identical, and the comparisons with the first column lead to similar conclusions. That was to be expected since, it will be remembered, the February, 1892, spectrum of *Nova Aurigæ* was largely chromospheric.

Aside from the hydrogen, $D_3$ and 4472 lines, the nebular spectrum* presents a few interesting coincidences with the Wolf-Rayet spectrum. The lines at 5412 and 4687 observed in several nebulæ were found with more or less prominence in nearly all the Wolf-Rayet stars; but the lines at 4389, 4067 and 4026 were found in only a few of the stars, and it is not certain that the last two lines occupy the same positions in the nebulæ and stars, though they probably do. The prominent star lines 5813, 5693, 5593, 5472, 4652, 4636, 4541, 4509, 4442 were specially searched for in the nebulæ and not found. Likewise, the nebular lines 5751, 5007, 4959, 4715, 4364 were most carefully looked for in the stars, and no trace of them is visible. I think we must

* See my paper on nebular spectra in the May and June, 1894, A. AND A.-P.

say that if any relation exists between these spectra, it is not clearly established and its nature is not apparent.

A comparison with the dark lines in the Orion type stars gives substantially the same results as obtained for the nebulæ, as would be expected from the close relationship of the nebular and Orion type spectra.* The presence of the lines 4688, 4652, 454, 4389, 4067 and 4026 in the two spectra must be given great significance. However, numerous strong lines in the Orion stars have not been found in the Wolf-Rayet stars and *vice-versa*, though careful search was made for them. The Orion star lines in column five are taken from my photographs of $\beta$, $\delta$, $\varepsilon$, Orionis and six stars in the dense parts of the Orion Nebula. I have not included lines contained in the spectrum of $\alpha$ Cygni: they are so numerous that, within the limits of observation errors, lines could be selected to match nearly all the Wolf-Rayet lines; but the same could be said of many other dark-line spectra. In looking for points of correspondence with the Orion type of spectrum, we should begin with the simpler types, such as that of $\delta$ Orionis, and work up gradually to the complex types, such as that of $\alpha$ Cygni. Until such observations are obtained, with wave-lengths accurate to four places, it does not seem advisable to hold that a closer relation exists between the Wolf-Rayet and Orion stars than between the Wolf-Rayet stars and the nebulæ.

The spectrum of $\beta$ Lyræ as observed by Dr. Belopolsky, Professor Vogel, Father Sidgreaves and others, shows considerable resemblance, in a general way, to the Orion type; and comparison with the Wolf-Rayet spectra leads to substantially the same results as were obtained for the Orion stars.

In conclusion, I think we can say, from the foregoing observations, that the spectra of the Wolf-Rayet stars are not closely related to any other known type. They appear to have several points in common with the nebular and Orion type spectra; but the last two appear to be much more closely related to each other than to the Wolf-Rayet spectra. It is therefore difficult to place these stars between the nebulæ and Orion stars. They certainly do not come *after* the Orion stars, and one does not like to place them *before* the nebulæ. We can probably say that the bright lines are chromospheric, owing their origin to very extensive and highly heated atmospheres, but showing very little relation, in constitution and physical condition, to that of our own Sun. For the present, at least, this type of spectrum must be consid-

* See A. AND A.-P. for May, 1894, pp. 395-7.

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ered as distinct from every other known type, just as the nebular spectrum is distinct, and like the nebular spectrum containing lines whose origin cannot now be assigned.

I wish to acknowledge having received a great deal of valuable assistance during the progress of the observations from Professor Holden, who was always ready to advance the work in every possible way. Likewise the large number of observations secured in the relatively short time devoted to the work is due to the efficient assistance received from Mr. H. D. Stearns of Stanford University, Dr. Mary Cunningham of Swarthmore College, Mr. S. D. Townley of Detroit Observatory, Secretary C. D. Perrine and Assistant Astronomer A. L. Colton of this Observatory. The last three have each assisted on from ten to twenty nights.

LICK OBSERVATORY, 1894, April 18.

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## ON THE SPECTRA OF THE ORION NEBULA AND THE ORION STARS.

JAMES E. KEELER.*

Notwithstanding the attention that spectroscopists have bestowed on the great nebula of Orion, there are still many unsolved questions relating to this most interesting object which may be dealt with by instruments of moderate power. The apparent simplicity of the spectrum first observed by Huggins in 1864 has been shown by the same eminent investigator to be due merely to the faintness of its light, the spectrum revealed by photography being one of considerable complexity. It is not yet known to what extent the spectrum of outlying portions of the nebula differs from that of the bright region near the trapezium, although Professor Campbell has shown that differences of spectrum do exist, at least in the intensity of the hydrogen lines as compared with the lines of other substances.† An anomalous spectrum photographed by Dr. Huggins in 1888 has not been accounted for.

One of the most interesting questions in connection with the great nebula is its relation to the surrounding stars. Photography has shown that the nebula extends far beyond the limits

* Communicated by the author.

† ASTRONOMY AND ASTRO-PHYSICS, Dec., 1893, p. 927. This seems to be an investigation particularly suited to large instruments, not because the spectrum is brighter with a large telescope, for this is not necessarily the case, but on account of the larger scale of the image on the slit-plate.

to which it can be traced by visual observation, and that many of the brighter stars in the same constellation, even those remotely situated, are involved in its outlying streamers. The inference is that the Orion stars occupy a place near the beginning in the scale of stellar development, and a study of the spectra of these stars, and particularly of any analogies that they exhibit with the spectrum of the nebula from which they have presumably been evolved, becomes of special importance. Some analogies of this kind have been traced, but our knowledge in this direction is very fragmentary, and, as I shall show, some conclusions that have been generally accepted are certainly erroneous.

For the purpose of throwing some light, if possible, on the interesting questions briefly alluded to above, I photographed the spectrum of the Orion nebula many times during the past winter with the spectroscope and 13-inch equatorial of the Allegheny Observatory, and although the results are far short of what I hoped to obtain, and are not at all in proportion to the considerable amount of time which has been expended on them, some facts of importance have been clearly brought out. The slowness of the work of observation is mainly due to the smoky atmosphere which surrounds this unfortunately situated Observatory, and which is particularly opaque to the photographically active rays. Nights on which photographic work in the upper spectrum can be pursued to advantage are of infrequent occurrence.

The spectroscope used in these observations was described in the January (1893) number of ASTRONOMY AND ASTRO-PHYSICS. The arrangement for photographing with a single prism is not illustrated in the plates; it is the same as the visual arrangement, except that the camera, of sixteen inches focus, is inserted in the place of the short observing telescope. In order to increase the stability, some light brass tubes, extending from the clamps in the frame near the slit to the clamps near the outer end of the camera, were added to the instrument. They are like the braces used with the prism train, except that they are very much longer, and they are secured in the same manner. By these rods the stability of the instrument was greatly increased; still the camera when used with a single prism is in a position unfavorable to rigidity, and care was therefore taken not to greatly change the position of the instrument during an exposure. By confining the observations to an hour angle of two hours on each side of the meridian, (and in the case of the Orion nebula an exposure of four hours was possible without reversing the telescope), the effects of flexure were

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prevented from becoming sensible. The effects of rapid changes of temperature were much more annoying.

All photographs of the spectrum of the nebula were made with a 60° prism of white flint glass. Some photographs of star spectra were made with a dense prism with considerably greater dispersion, and on one occasion the prism train was employed. The spectroscope has in all its essential features shown itself to be entirely satisfactory, and well adapted to the various purposes for which it is used. Unfortunately the same statement cannot be made with regard to the telescope. The figure of the objective is good, but the glass is quite yellow, the crown lens in particular being so yellow that I cannot help thinking that it must have undergone a change in color since it was made, some twenty-five years ago. For most kinds of visual observations this yellow tint of the objective is rather advantageous than otherwise, as it cuts down the secondary spectrum, but it is obviously anything but an advantage in photographic work. The mounting of the telescope has been brought up to modern requirements as nearly as circumstances permit, and is quite satisfactory.

The spectrum of the nebula on the photographic plate was about an inch long (23 mm. from the chief nebular line to the farthest line in the ultra-violet); its breadth was varied to suit the requirements of observation.

The object of my earlier observations, some of which were made in the winter of 1892-93, was to reproduce, if possible, the anomalous spectrum obtained by Huggins in 1889, and to determine the position and extent of the regions in which this spectrum might be found. In the spectrum photographed by Huggins, to which reference is made above, no trace of the hydrogen lines H$\delta$ and H$\varepsilon$ could be found, although H$\gamma$ was strong, and a large number of fine lines, apparently connected with the spectra of the trapezium stars, were visible; the strong line previously photographed, at $\lambda$ 373, was absent. In 1890 the spectrum of nearly the same region was of the usual character. Although this sudden termination of the hydrogen series, evidently not the result of increasing faintness of the lines, seems very remarkable, the extraordinary fact discovered by Campbell, that both bright and dark hydrogen lines can exist in the same spectrum and in the same series, as well as less striking anomalies which have been remarked by other observers, show that *a priori* reasoning on the probability of such an occurrence must be used with great caution. I therefore tried to obtain the same result by repeating the observations of Huggins.

In the photographs which I took for this purpose, the slit was always placed in an east-and-west direction, and it was opened to its full length, so that it extended entirely across all the brighter part of the nebula. The width was .005 inch. With the aid of the finder of the equatorial, the center of the slit was kept in the hour circle passing through the trapezium, and in a parallel of declination which had been previously decided upon. The declination was altered at each exposure, and thus by successive steps the whole of the brighter region in the vicinity of the trapezium was fairly well covered. On account of bad weather many of the photographs were failures, and had to be repeated.

I expected that the region in question, if it fell upon the slit during one of these exposures, would reveal itself on the plate by the presence of breaks or gaps in the hydrogen lines above H$\gamma$ and in the line $\lambda$ 373, and from these gaps the position of the region could be determined. No such appearances were, however, to be found on any of the photographs; the spectra were essentially all of one type, and the differences which they exhibited were only such as would naturally seem to accompany the varying brightness of the source. The type referred to is a spectrum in which the hydrogen lines are very strong, the series toward the violet falling off gradually to invisibility; the first and second nebular lines of the visual spectrum are also strong, especially with orthochromatic plates, and the ultra-violet line at $\lambda$ 373 is distinct, although, (with my apparatus), not nearly equal to the lower hydrogen lines in strength. These lines represent by far the greater part of the radiation from the nebula.

It appears then from these observations, that the area of the region in question is very small, or that the spectrum of the nebula is subject to rapid and considerable changes. There remains the possibility that the abnormal spectrum of 1889 was an idiosyncrasy of the particular plate on which it was obtained —an explanation which is suggested by various puzzling phenom- that I have come across in my own experience, but one which I should be much more ready to adopt if the photograph had been one of my own making.

The photographs made in connection with this investigation do not show any remarkable differences in the spectrum east and west of the trapezium; on the preceding side the lines are stronger, corresponding to the greater brightness of the nebula in that region, and fainter lines appear, but the differences seem to be merely such as depend upon brightness. The variations in the density of the lines, found by Dr. Huggins to be due to the

irregular brightness or mottled surface of the nebula, is not very noticeable in my photographs, probably because the telescope was not directed in right ascension with sufficient accuracy by means of the finder to prevent a drift of the image; moreover, the slit-plate was in the focal plane of the H$\gamma$ line, and the images of the nebula corresponding to the other hydrogen lines were somewhat out of focus.

One of the objects of these observations was to determine as accurately as possible the positions of the fainter nebular lines, which are still subject to considerable uncertainty.* For this purpose the same arrangement of apparatus was employed; but the slit was shortened to about one millimetre, and after the exposure to the brightest part of the nebula, the telescope was either turned to the Moon, or allowed to remain untouched until morning, and the solar spectrum was then photographed with a longer slit, the central millimetre being covered by the metal tongue described in a previous account of the Allegheny spectroscope. The result was two parallel solar spectra about a millimetre wide and the same distance apart, connected by the sharp, black lines of the spectrum of the nebula.

The plates obtained in this way were measured with a small comparator by Zeiss, which had been exhibited at the Chicago Exposition, and which I purchased for the Observatory. It consists essentially of a strong stand, holding two fixed microscopes provided with eye-piece micrometers, and a sliding stage with a range of one decimeter. The photograph to be measured is mounted on one end of the sliding stage and viewed with one of the microscopes; the other microscope serves to read the scale, which is cut in a strip of silver let into the stage. One revolution of the scale micrometer is equal to 0.1 mm., and one division is equal to 0.001 mm. I have investigated the scale and micrometer screws far enough to ascertain that they contain no errors which need be considered in reducing the measures of these photographs. Both microscopes have a power of about 30, and as this is in general too high for weak lines on a negative, I had an additional short microscope made, which carries the same micrometer as the one it replaces, and which is furnished with a draw-tube, so that the power can be varied from 7 up to 25 diameters. The micrometer of this microscope carries a close pair of fine wires.

* The most complete lists of the nebular lines are by Dr. and Mrs. Huggins, *Proc. Roy. Soc.*, vol. 46, p. 40, and vol. 48, p. 213; Professor Lockyer, *Proc. Roy. Soc.*, vol. 48, p. 199, and *Phil. Trans.*, vol. 184, p. 675; Professor Campbell, ASTRONOMY AND ASTRO-PHYSICS, vol. 12, p. 722.

The nebular lines were observed by bringing them between the wires; the solar lines by bisecting them with each wire in succession.

This instrument is well adapted to the measurement of small photographs. As compared with such a measuring instrument as that used at Potsdam, it has the disadvantage of requiring two settings,—one with the viewing and one with the scale microscope; on the other hand the photograph can be moved rapidly through the field of the viewing microscope, and this motion, in addition to its convenience, is of advantage for detecting faint lines, which would otherwise escape notice.

Wave-lengths were determined from the photographs in the following manner: one of the plates, on which the solar spectrum was particularly sharp, was chosen as a standard, and from measurements of a large number of solar lines between F and $\lambda$ 370 a wave-length curve was platted, on a scale large enough to bring out the errors of measurement. As plates taken on different nights and at different temperatures were generally made with slightly different adjustments of the instrument, their scales did not exactly correspond with that of the standard plate; moreover the nebular lines were slightly displaced relatively to the solar spectra, owing principally to changes of temperature in the interval between the exposures, and to motion in the line of sight. For any plate, measures of a considerable number of the standard lines gave the reductions to the scale of the standard plate, and the measured displacements of the sharpest hydrogen lines of the nebula gave the small corrections, nearly constant throughout the spectrum, which were to be applied to the positions of the nebular lines, and in which were included the effects of flexure, changes of temperature, curvature of the lines, and motion in the line of sight.

Notwithstanding the small scale of the photographs, the wave-lengths could be determined in this manner with considerable accuracy. For sharply defined lines the results of different plates differed by but a small fraction of a tenth-metre; for faint lines they were greater, but the different measures were generally within one tenth-metre; in some cases the discrepancies exceed this limit. At the end of the present article I have indicated the manner in which I think extreme accuracy will finally be reached.

On account of the unfavorable conditions already referred to, it was difficult to obtain in one evening a photograph sufficiently intense to show the fainter nebular lines, and I therefore tried to see how far it might be possible to compensate for these disad-

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vantageous circumstances by continuing an exposure from night to night, in the manner that has become familiar in ordinary stellar photography. The experiment was not a success. Several cloudy nights often intervened between the exposures, the temperature meanwhile varying greatly, and the result was a series of partly overlapping images or confused lines, the intensity of which was not specially greater than that of any single image, while the photograph was unfit for accurate measurement. The longest exposure given to any plate was $14^h\ 45^m$ on four different nights in February; the slit was wide, and the lines are strong but very much blurred. One plate, exposed $7^h$ on two consecutive nights which happened to be of nearly the same temperature, is fairly good, but the sky was quite smoky at times, and a considerable part of the exposure certainly counted for very little. On the former of these occasions an orthochromatic plate was used, in the hope of catching the $D_3$ line, or some of the lines in the lower spectrum described by Taylor,* but without result in this respect, although the chief nebular line is very black and strong and the maximum sensitiveness of the plate falls at some distance below this point, at about midway between *b* and D. It is to be noted that the absorptive action of the atmosphere and of the glass of the objective is far less marked in this region than near H$\gamma$. While the $D_3$ line falls too near the lower limit of sensitiveness to make its non-appearance worthy of remark, it would seem that the other lines, if they really exist, should be seen in this photograph, although it certainly is not easy to estimate their relative photographic and visual values.

As I have not been able to find any data regarding the slit-widths used by different observers, some experiments which I made in this connection may not be without interest. According to the principles of the undulatory theory, the full illumination of bright line is reached when the slit, as seen from the optical centre of the collimator, subtends the same angle as one wave-length of light at a distance equal to the (effective) collimator aperture. With my instrument this slit width is about .0003 inch. Experiment showed, however, that with the same exposure the density of the photographed lines began to fall off sensibly when the slit-width was reduced below .001 inch, or when it was still three times the theoretical width. In these photographs the exposures were comparatively short and and there was no evidence of shifting of the image. The discrepancy is, I suppose, to be attributed

* *Monthly Notices*, R. A. S., vol. XLIX, p. 126.

to the effect of spreading of the photographic image, each particle of silver being deposited partly by the influence of neighboring illuminated particles, which are fewer in number when the slit is narrow; the physiological effect on the retina which makes a line appear brighter when the slit is widened in visual observations, seems to be analogous to this photographic action. The slit-width which gave the best results was about .0015 inch.

In the following table are given the results of my measurements. The estimated intensities are given for an orthochromatic plate obtained on January 25, 1894, 100 representing complete opacity of the silver deposit, and 1 a scarcely visible trace. While these numbers have no special physical significance, depending as they do upon the atmospheric conditions, the absorption of the instrument, and many other factors, they serve to convey an idea of the appearance of the plate, and they illustrate the very great differences in the intensities of the lines. It is evident that almost all the light of the nebula is derived from hydrogen and the substance or substances yielding the two principal lines of the visual spectrum.

On one of the best negatives taken on February 10, 1894, the ultra-violet line at $\lambda$ 373 is distinctly double, the upper component being somewhat the stronger. I have been unable to account for this circumstance, as the other hydrogen lines are single and sharp, and so are the solar lines of the comparison spectrum in the same region. On all other photographs the line is single, and I have therefore ascribed its appearance on the negative of February 10 to some accidental cause, perhaps a shred on the plate. According to my experience, faint details on a single negative are to be regarded with some suspicion, particularly if the plate has received insufficient exposure. In the table I have, however, given the measures of the two components of this line on the negative referred to, as well as the position of the single line from the mean of other negatives. The hydrogen lines up to and including H$\varepsilon$ have been used in determining the corrections for displacement, and of course their wave-lengths have been assumed as known; above H$\varepsilon$ they are determined from the measurements. The wave-lengths of the two lowest nebular lines are also assumed, as the accuracy of my former visual measurements with high dispersion much exceeds that of the present photographs.

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POSITIONS OF LINES IN THE SPECTRUM OF THE NEBULA OF ORION.

| Wave-length. | Estimated Intensity. | Remarks. |
|---|---|---|
| 3728.0 | | Photograph of Feb. 10. |
| 3725.8 | | |
| 3726.5 | 35 | Other photographs. |
| 3800 | 1 | H9 |
| 3814 | 1 | Very faint line, possibly accidental. |
| 3836 | 3 | H$\eta$ |
| 3868.9 | 20 | |
| 3889.2 | 20 | H$\zeta$ |
| 3970.0 | 40 | H$\varepsilon$ |
| 4026 | 4 | |
| 4069 | 5 | |
| 4102.0 | 60 | H$\delta$ |
| 4340.6 | 100 | H$\gamma$ |
| 4365 | 5 | |
| 4471.2 | 10 | |
| 466 ± | 3 | Position estimated. |
| 4716 | 4 | |
| 4861.5 | 40 | H$\beta$ |
| 4959.0 | 30 | Second nebular line. |
| 5007.1 | 100 | Chief nebular line. |

The line at λ 446 appears upon only one of the photographs, which was taken with a rather wide slit, and with long exposure. The lines are confused, and unsuitable for measurement. There is a streakiness in the spectrum at several places in this region, on the background of continuous spectrum from one of the trapezium stars, which seems to indicate that other lines might be brought out under more favorable conditions.

On several of the negatives made, in the course of the investigation first mentioned, with a rather wide slit, into which the stars of the trapezium had occasionally wandered, there was a mottled appearance in the spectrum just below the H$\gamma$ line, which I should have attributed to photographic defects if it had appeared on a single negative; but as it was evidently real, I concluded that it was caused by the presence of both dark and bright lines, blended into a confused image by the wide slit and imperfect guiding. This seemed to be the only satisfactory explanation, notwithstanding the fact that the trapezium stars have hitherto been supposed to give spectra in which the nebular lines are bright. Another plate, taken with a narrow slit, (.0015 in.), accurately directed to the brightest star in the trapezium, justified this conclusion; broad diffuse dark lines were seen in the star spectrum, some of which were traversed centrally by the bright lines of the nebula, so that they presented much the same appearance as the hydrogen lines in the spectrum of $\gamma$ Cassiopeiæ or Pleione.

The following table contains a list of these lines. As they are very broad and diffuse, their wave-lengths could not in general be measured with much accuracy.

DARK LINES IN THE SPECTRUM OF THE TRAPEZIUM STAR BOND 628.

| Wave-length. | Remarks. |
|---|---|
| 3970 | H$\varepsilon$. Crossed by bright nebular line. |
| 4102 | H$\delta$. " " " " " |
| 4201 | Doubtful. |
| 4341 | H$\gamma$ Crossed by bright nebular line. |
| 4369 | Suspected. |
| 4388 | Strong dark line. |
| 4471 | Crossed by bright nebular line. |
| 4542 | Strong dark line. |
| 4650 | " " " |
| 4685 | " " " |
| 4716 | " " " |
| 4862 | H$\beta$. Crossed by bright nebular line. |

The spectra of other stars in the trapezium were also photographed, and while the results were imperfect, on account of the faintness of the stars, and for other reasons mentioned below, they sufficed to show that the spectra are all of essentially the same type.

In 1890 I had already found dark hydrogen lines in the spectrum of $\Sigma_2$ Orionis (Bond 685) by visual observation with the Lick telescope. Hence it seems to me that Espin's observation of bright lines in the spectra of $\Sigma_1$ and $\Sigma_2$ Orionis, announced in Wolsingham Observatory Circular, No. 26*, must be a mistake.

The lines in the above table are prominent lines in the spectra of other Orion stars, and their evident relation to the bright lines of the nebular spectrum led me to examine other stars in the same constellation, with the purpose of tracing these spectral analogies still farther. Professor Scheiner had already pointed out† that a line in the nebular spectrum measured by Copeland at $\lambda$ 4476 was probably identical in position with a strong line which is characteristic of the Orion stars, and which according to the Potsdam photographs has a wave-length of 4471.36. According to my measurements the wave-length of the nebular line is 4471.2, Campbell‡ makes it 4473 in the Nebula of Orion and 4472 in some other nebulæ. There is no doubt therefore that Scheiner is right in his conjecture, and that the lines are identical in origin. But in the case of Bond 628, the coincidence of these lines is shown more beautifully by inspection

* A. N. 2963.
† *Spectralanalyse der Gestirne*, p. 267.
‡ ASTRONOMY AND ASTRO-PHYSICS, October, 1893.

of one of my photographs than by any process of measurement. The sharp nebular line fades away toward the star spectrum, and stops just before reaching it, pointing like an arrow exactly at the center of the gap in the continuous spectrum.

In photographing star-spectra with a visually corrected telescope, difficulties are met with which do not occur when the object is an extended surface like the nebula of Orion. In the upper part of the spectrum the focus changes rapidly with the wave-length, and only one set of rays can be accurately focused on the slit. Hence the proper exposure can be given to only a very limited range of spectrum, all other parts being under-exposed and weak. The only remedy is to make a number of different exposures with the slit-plate in different positions; but this piece-meal representation of the spectrum by a series of negatives is a very imperfect substitute for the single plate which would be obtained with a photographically corrected telescope. Estimates of the relative intensities of lines are also seriously embarrassed. These remarks do not apply to the lower part of the spectrum which can be photographed with orthochromatic plates. Here the case is reversed, and the visual telescope has the same advantage that the photographic telescope has in the blue and violet regions.

In photographing star-spectra I followed the same method as in the case of the nebula, a solar comparison spectrum being photographed on each plate. Both prisms were used at different times, and the small dispersion and other circumstances already referred to gave rise to some differences in the appearance of the spectra, as compared with those obtained with higher dispersion. In the main they are no doubt purely photographic. Thus, with a single prism the various intensities of lines in the spectrum of Rigel appear as differences in breadth; while with the prism train, which was used on some occasions, the lines are of the same breadth but differ in intensity, having the appearance described by Professor Scheiner.* The hydrogen lines in the spectrum of ζ Orionis are, according to Scheiner, so diffuse and faint that they are barely visible; on my plates, taken with small dispersion, they are very conspicuous.

It was obviously a matter of the greatest interest to determine whether the chief nebular lines at λ 4959 and λ 5007 are reversed in the spectrum of any of the Orion stars. On all the plates which were good enough to be of real value in deciding this point

* *A. N.* 2923.

—namely, those of $\beta$, $\gamma$, $\varepsilon$ and $\zeta$ Orionis,—no traces of dark lines at these places could be found; the star spectra were continuous.

On photographs of the lower spectrum of Rigel a strong line was shown just above the D lines of the comparison spectrum. The analogies with the nebular spectrum already discovered, together with the fact that the $D_3$ line has been observed in the spectrum of the Orion nebula, led me at once to suspect that this line was $D_3$, and on account of the interest that attaches to everything connected with this remarkable line, I took some pains to measure its position with all possible accuracy. It is true there is a general belief that $D_3$ is never reversed in star-spectra* but our knowledge of the lower spectra of the stars is very imperfect. I have recently shown that there is reason to suppose that $D_3$ is dark, as well as bright, in the compound spectrum of $\beta$ Lyræ.†

The method of determining wave-lengths hitherto employed was inapplicable in this case, for the lower spectrum of Rigel is almost blank, and when the D lines were brought to the centre of the field, and the instrument was specially adjusted for this part of the spectrum, only the F line was common to both spectra, the other hydrogen lines being off the plate, hence the relative displacement of the spectra could not be determined with sufficient exactness. The lines of sodium were therefore photographed on the plate as a comparison spectrum, and in reducing the measures, allowance was made for the effect of motion in the line of sight. I also made some visual measures with the single dense prism and with the prism train, and finally photographed the spectrum with the prism train, with the sodium lines for comparison. With this last arrangement the stability of the instrument is very great, as I think is apparent from the construction as shown on plate VII in No. 111 of this journal. It is shown by the great sharpness of the lines in the lower spectrum of a star like Arcturus when photographed with the same arrangement, and I have tested it directly by experiments with the solar spectrum, showing that the displacement caused by *twice* the *maximum* flexure is all but invisible under the microscope. The scale of the photographs is a little greater than that of the Potsdam photographs in the same part of the spectrum. The distance between tke D lines is 0.153mm.

An excellent photograph was obtained with this arrangement on the evening of March 23. The exposure was $1^h\ 30^m$ with a

* *Spectralanalyse der Gestirne*, p. 277.

† Astronomy and Astro-Physics, April 1893.

slit-width of .001 inch. A feeble sodium flame was held in front of the slit for 3 minutes before the exposure and again for 3 minutes after the exposure was completed. Both the star and the sodium lines were sharp, and suitable for exact measurement. The reduction was effected with the aid of a solar spectrum taken on the following morning.

In allowing for the effect of motion in the line of sight, I have used the motion of the star relatively to the Sun as determined by the Potsdam observers. The total motion to be allowed for is then as follows:

| | |
|---|---|
| Earth's orbital motion | + 15.11 miles. |
| Diurnal rotation (hour angle + 3$^h$) | + 0.16 " |
| Motion relative to Sun (Vogel) | + 10.14 " |
| | + 25.41 " |

This velocity corresponds at $D_3$ to a displacement of 0.80 tenth-metres toward the red. The apparent wave-length of the star-line, from the measurements, was 5876.78; hence the true wave-length is 5875.98.

The results of the different measures are given below:

| | | |
|---|---|---|
| March 16, 1894. | Single prism, visual observations; weight 1 | $\lambda$ 5875.9 |
| March 20, " | Single prism, photograph; weight 2 | 5875.8 |
| March 21, " | Single prism, photograph; weight 2 | 5876.4 |
| March 23, " | Prism-train, visual observations; weight 10 | 5875.98 |
| March 26, " | Prism-train, visual observations; weight 2 | 5876.1 |
| | Mean by weights | 5876.02 |

The assignment of weights is somewhat arbitrary. There is no doubt, however, that the determination with the prism train greatly exceeds the others in accuracy, and with this fact taken into account, any other system of weights gives practically the same result.

According to Rowland, the wave-length of the $D_3$ line is 5875.98; hence I think there can be no doubt that the dark line in the spectrum of Rigel is actually $D_3$.

Some other lines below $D_3$ were seen in the visual observations, and appear on the photographs; they are much fainter than $D_3$. I believe that the D lines of sodium are present, but very faint, although I am not certain on this point; in my best photographs they are obscured by the intense lines of the artificial sodium spectrum. As no list of lines in the lower spectrum of Rigel has been published, I give below the results of my photographic measures. The wave-lengths are generally subject to some uncer-

tainty, and the relative strengths given for the lines have little meaning, for reasons which have already been stated. Above H$\gamma$ I have not thought it worth while to give any measures, as this region has been covered by the Potsdam observations, the accuracy of which is much greater than that of mine. In the future I hope to amend the results in the table by repeating the observations with the prism train.

LINES IN THE LOWER SPECTRUM OF RIGEL.

| Wave-length. | Remarks. | Wave-length. | Remarks. |
|---|---|---|---|
| 4341 | H$\gamma$. Very strong. Neb. | 4924 | Fairly strong. |
| 4352 | Very weak. | 5016 | Strong. |
| 4389 | Neb. Fairly strong. | 5033 | Very weak. |
| 4418 | Very weak. | 5056 | Weak. |
| 4425 | Very weak. | 5168 | Fe? Fairly strong. |
| 4439 | Weak. | 5316 | Weak. |
| 4448 | Weak. | 5454 | Weak. |
| 4471 | Neb. } Strong equal pair | 5876 | $D_3$. Neb. Very strong. |
| 4481 | Mg } | 5890? | $D_2$ } Suspected. |
| 4509 | Very weak. | 5896? | $D_1$ } |
| 4548 | Weak. | 5902 | Weak. |
| 4583 | Weak. | 5925 | Weak. |
| 4714 | Neb. Strong. | 5959? | Suspected; weak. |
| 4861 | H$\beta$. Neb. Very strong. | | |

In this table lines coinciding in position with the bright lines of the nebula are marked "neb." A line at $\lambda$ 4389 does not appear in my photographs of the spectrum of the nebula, but a line in this position has been photographed by Campbell.* The strong line $\lambda$ 4481 is also strong in the spectrum of Sirius. Scheiner, who makes its wave-length 4481.4, identifies it with the solar line 4481.41, and regards it as probably due to magnesium. No traces of the characteristic magnesium group *b* are however to be found on my photographs. The only line in the region is nearly coincident with $b_4$; it is perhaps the iron line $\lambda$ 5167.69, which is relatively stronger in the arc specrum than in the Sun; but I am inclined to doubt whether any of the lines in the spectrum of Rigel are due to iron.

The relationship between the bright nebular lines and dark lines in the spectra of the Orion stars is more apparent when the spectra are exhibited in a drawing, with proper attention given to the relative intensities of the lines, than it is when the comparison is made by means of tables. I shall however content myself with a review of the nebular lines, pointing out for each line the coincidences with dark lines, as determined from the photographs.

* ASTRONOMY AND ASTRO-PHYSICS, Oct. 1893, p. 723.

## Comparison of Nebular Lines with Dark Lines in the Spectra of the Orion Stars.

λ 3726.5. This is the most refrangible line that appears on my photographs, and at the same time it is a strong one. Observers whose instruments are specially free from selective absorption in the violet have described it as the strongest line in the photographic spectrum. The same line is found in planetary nebulæ. It would be of great interest to determine whether there is a corresponding dark absorption line in the star spectra; but unfortunately the difficulties of photographing at so short a wave-length with a a visual telescope are very great, and I have not succeeded in obtaining any negatives that are good enough to decide this point, nor have I found any published record of measurements in this part of the spectrum of Orion stars.

λ 3800, H$\zeta$ (3798.1). In the nebular spectrum the hydrogen series fades off gradually toward the violet, and no doubt still higher members would appear with longer exposures under more favorable circumstances. As the hydrogen lines are found in practically all star spectra, their presence in the Orion stars has no special significance in this connection. No mention will therefore be made of the remaining hydrogen lines.

λ 3814. (?). This is a very faint line on one of my photographs, and it may be accidental. If real, it is probably identical with Pickering's "Orion line" λ 382.

λ 3868.9. A strong line forming an equal pair with H$\zeta$. It is above the limit of my star photographs.

λ 4026. A strong isolated dark line is found at this place in the spectrum of Rigel (λ 4026.6, Scheiner). The same line is very strong and broad in $\zeta$ Orionis, and strong in $\varepsilon$ Orionis, no other strong lines being in the vicinity in either case. It is also strong in $\gamma$ Orionis, the nearest line at all approaching it in intensity being 17 tenth-metres above.

λ 4069. This nebular line is represented by a fairly strong dark line in $\zeta$ Orionis, many weaker lines being in the vicinity. It is strong and diffuse in $\varepsilon$ Orionis, weak in $\gamma$ Orionis, although stronger than neighboring lines; in Rigel it does not appear on my photographs, and it is not in Scheiner's catalogue of lines in the upper spectrum of this star.

λ 4130. Professor Lockyer* has photographed a number of presumably very faint lines in the spectrum of the Orion nebula,

* Phil. Trans., Vol. 184.

having the wave-lengths 4045, 4130, 4142, 4155, 4167, 4188, 4200, 4268, 4690, 4735. With the exception of λ 4142, these lines do not seem to be uniformly represented in the spectra of the Orion stars, unless the lines are too weak to appear on my photographs. There is a fairly strong line in ζ Orionis at λ 4143.5, and a broad weak line at λ 4187. λ 4200 (4201, 4201.5) seems to run through the series with the exception of Rigel. λ 4131.0 is strong in the spectrum of Rigel, but I do not find it in other stars. The remaining lines are represented in some doubtful cases. For this reason and on account of their faintness they are not considered separately.

λ 4365. This is represented by a diffuse line in the spectrum of ε Orionis, and probably by a line in the brightest trapezium star, although the measured wave-length (4369) of the latter is not in very good agreement. I do not find it in β, ζ and γ Orionis.

λ 4390. Professor Campbell has photographed a line at this place which does not appear on my plates. It corresponds with strong absorption lines in β, ε, ζ and γ Orionis; in γ it is particularly strong and sharp. There is also a strong absorption line at this place in Bond 628. The wave-length given above is somewhat too great, according to my measures of the stellar lines; in Rigel, Scheiner makes it 4388.5.

λ 4471.2, (4471.36). This corresponds with one of the characteristic Orion lines, and its exact coincidence with the dark star-line in the case of Bond 628 has already been mentioned. It is a strong line in all the Orion stars I have examined.

λ 466 ±, (4661, Campbell). The nebular line, on the only plate of mine on which it appears, is too faint and blurred for measurement. I do not find star-lines at this place, but there is a very strong line at λ 4650 in ε and ζ Orionis and Bond 628.

λ 4716. A prominent line at this place seems to run through all the Orion stars. It is represented in β, γ, δ, ε, ζ Orionis and Bond 628.

λ 4959.02, λ 5007.05. The two principal lines of the visual spectrum are not represented by absorption lines in any of the stars.

λ 5875.98 The $D_3$ line is dark in the spectrum of Rigel. I have not yet been able to ascertain whether it is present in other Orion stars.

The comparisons which have been made above demonstrate the intimacy of the relation which exists betwen the Orion nebula and the neighboring stars; indeed, taking into account the rela-

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tive intensities of the lines, the spectrum of Rigel may almost be regarded as the nebular spectrum reversed. Even $D_3$ is represented by an absorption line, but an exception must be made of the two chief lines in the visual spectrum, which do not seem to be reversed under any circumstances. It is not improbable that other nebular lines will be found at places corresponding to strong lines in other Orion stars, as for instance at $\lambda$ 4650.

Professor Lockyer has given a table of lines common to the Orion nebula and $\alpha$ Andromedæ, but it seems to me that such identifications, in the case of a star like $\alpha$ Andromedæ, whose spectrum is full of fine lines of nearly equal intensity, and with uncertainties of at least one tenth-metre in the positions of most of the nebular lines, are little better than guesswork. In the case of the Orion stars the conditions are very different. The spectra are nearly blank, and the lines corresponding with the nebular lines are in general isolated and conspicuous; an error of one tenth-meter can hardly lead to an erroneous conclusion.

As to the chemical significance of these lines, it seems to me that at present little can be said, for with a few exceptions their wave-lengths have not yet been determined with the necessary accuracy. The exact wave-lengths can however be ascertained by means of the Orion stars. Although in these stars the known lines capable of serving as reference points are few in number, measurements of considerable precision can be made with their aid, as in the case of Rigel at the Potsdam Observatory; with the positions obtained in this way the lines can be certainly identified in the spectra of stars which also contain a large number of solar lines, and in these spectra the lines in question can be measured with the requisite precision.

Some of the observations which I have described have an important bearing on theories of stellar development. It has been shown that contrary to the belief which has been held up to the present time, the trapezium stars have spectra marked by strong absoption bands; they have not the direct connection with the nebula that would be indicated by a bright line spectrum, but are in fact on precisely the same footing (spectroscopically) as other stars in the constellation of Orion. While their relation to the nebula is more certain than ever, they can no longer be regarded as necessarily situated *in* the nebula, but within indefinite limits they may be placed anywhere in the line of sight. It should be noted that the broadness of the absorption lines precludes the supposition that the absorption is due merely to the nebula, the stars being situated on the opposite

side from the earth. In that case the dark lines would or would not appear, according to the preponderance of the stellar or nebular radiations as seen from the earth, but in any case they could not exceed the nebular lines in width; hence the absorption has its origin in the atmosphere of the star itself.

It might be supposed that the star lines are doubly reversed, as in Pleione, in which case the bright lines would not be seen, on account of the nebular lines superposed on them. A brightening of the nebular lines would however result, which is not found on the photographs; moreover no central brightening is seen in those dark lines which are not traversed by the lines of the nebula. The supposed condition is not in itself very probable.

With regard to the appearances that have led to the belief that the nebular lines are bright in the spectra of these stars, I believe that they are of physiological and photographic origin. To me, as well as to other observers, the nebular lines (including H$\gamma$) have always appeared brighter where they were crossed by the star spectra, but this appearance is certainly an illusion, for the star line at H$\gamma$ is dark, although so broad and diffuse that it would easily escape detection by visual means. Possibly it is this unnoticed darkening of the background that causes the nebular line in its center to look unusually bright, while the spreading of the photographic action from the star spectrum outward along the nebular lines, may be the cause of the similar appearance that has been observed on photographs.

Finally I may observe that the discovery of the true nature of the spectra of these stars removes a certain difficulty that existed in connecting the Orion nebula with the system of stellar evolution. According to Professor Pickering* the spectra of ninety-nine one-hundreths of the stars can be imitated by combining in different proportions four sets of lines, one set being the characteristic lines of the bright stars in Orion. Hence the Orion stars are in the direct line of promotion. But the spectrum formerly ascribed to the stars of the trapezium differed from that of bright-line stars of the usual type, and seemed to indicate that the first stage of condensation was not the same as in other gaseous nebulæ. This difficulty is therefore removed. The first step in the formation of the Orion stars may be a bright-line star of a type already known; it has however not been observed.

* Astronomy and Astro-Physics, October 1893, p. 719.

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## SPECTRA OF THE GREAT NEBULA IN ORION AND OTHER WELL-KNOWN NEBULÆ.*

W. W. CAMPBELL.

### The Planetary Nebula, SDM. — 12°, 1172.

This nebula was discovered by Mrs. Fleming on the Harvard College Observatory plates by means of its spectrum of bright lines, and attention was called to the fact that its H$\beta$ hydrogen line is unusually bright.†

It is a beautiful object as seen in the 36-inch telescope, consisting of a 9th magnitude star surrounded by a circular disc of blue light nearly 15″ in diameter. In the spectroscope, with open slit, the well-known nebular lines at wave-lengths 5007, 4959 and 4861 are seen as circular discs, of which the last is considerably the largest in diameter. The diameters of the three discs were measured with the micrometer, on Nov. 2, 1893, and found to be about 11″, 9″ and 14″ respectively. The relative intensities of the light in the three discs were estimated at 10 : 3 : 7. A wedge photometer of increasing darkness was moved over the eye-piece at right angles to the line joining the three discs; and the fact that the disc at 4861 disappeared before the disc at 5007 did, proves that the latter is the brighter. All of the discs are brightest at the centers and fade away gradually as the edges are approached, as would be expected; but the hydrogen disc 4861 is of much more uniform brightness throughout than the other two.

The relative diameters and intensities of these discs are very important, in that they make it almost certain that the incandescent hydrogen which furnishes the disc 4861 forms the outer shell or layer of this nebula, and that the unknown gases which furnish the discs 5007 and 4959 must for the most part lie within the hydrogen exterior.

It should be pointed out that this nebula is very near the nebulous regions of Orion. The hydrogen lines are relatively very strong in the Orion nebula spectrum, also, and a possible common origin of the two objects is suggested.

The other hydrogen lines H$\gamma$, H$\delta$ and H$\alpha$ are visible in this spectrum, but the last two are very difficult. No other lines were seen with certainty, and no photographs were secured. No bright lines were seen in the stellar spectrum.

* Communicated by the author. [Continued from page 398.]

† *Astronomische Nachrichten*, No. 3049.

### The Planetary Nebula in Draco, G. C. 4373.

Great interest attaches to this object, both from its remarkable form,* and from the fact that this was the first nebula to be studied spectroscopically, by Dr. Huggins† in August, 1864.

I obtained visual observations of its spectrum in Sept. and Oct., 1893. In addition to the three well-known lines, I was able to observe six other bright lines at H$\alpha$, $D_3$, $\lambda$ 5750, $\lambda$ 4688, $\lambda$ 4472, and H$\gamma$, of which all but the last one are difficult. The "traces of lines at 527, 518, 509 and 479" observed by Vogel‡ were not visible to me. H$\alpha$ is extremely faint. $D_3$ and $\lambda$ 575 were observable only when the bright central star was just outside the wide slit, and were not visible at all when the star spectrum was in view. Those bright lines are due, therefore, to the nebula proper, as indeed are all the lines observed, and there is no evidence to show that they exist at all in the central star. When the spectrum is observed with an open slit, there are three well-defined, bright, monochromatic images of the nebula formed at $\lambda$ 501, $\lambda$ 496, $\lambda$ 486. The continuous spectrum of the star crosses these images, but no brightenings are visible at their centres, as would be the case if the nebular lines were present in the star.

Further, when the slit is made extremely narrow, the middle of each narrow nebular line is only very slightly brighter when the star is in the slit than when it is just outside. When the slit is wide and the star is just outside the slit the continuous spectrum of the nebula is very easily seen.

The estimated relative intensities of the principal bright lines are 10 : 3 : 2.

Two photographs were obtained, in May and September, 1893. A list of the bright lines observed is as follows, the first three having been obtained visually.

Table IV.—Bright Lines Observed in G. C. 4373.

| | | |
|---|---|---|
| | 6560 | H$\alpha$, extremely faint. |
| | 5879 | $D_3$, very faint. |
| | 5750 | Very faint. |
| 5007 | 5007 | 1st nebular line, very bright. |
| 4959 | 4959 | 2d nebular line, very bright. |
| 4861 | 4861 | H$\beta$, very bright. |
| | 4716 | Very faint. |
| | 4688 | Faint. |
| | 464 | Very faint. |
| 4472 | 4472 | Bright. |

* Described by Professors Holden and Schaeberle in *Mon. Not. Roy. Ast. Soc.* vol. 48, pp. 388-91.

† *Philosophical Transactions*, 1864, p. 438.

‡ *Astronomische Nachrichten*, vol. 78, p. 246.

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| | | |
|---|---|---|
| 4363 | 4363 | Faint. |
| 4341 | 4341 | Hγ, very bright. |
| 4102 | 4102 | Hδ, very bright. |
| 4067 | 4067 | Bright. |
| 4026 | 4026 | Bright. |
| 3969 | | Hε, very bright. |
| 3888 | | Hζ, bright. |
| 3867 | | Bright. |

Eleven of these bright lines appear not to have been observed by others. The lines at λ 5007, λ 4959, λ 4861 are those first observed by Huggins in 1864. Von Gothard* photographed lines at 434, 410, 3965, 3865, 373, in October, 1892.

### The Planetary Nebula, G. C. 4390, (Σ6).

This interesting nebula is nearly elliptical in outline, and near its centre the nebulosity is exceedingly condensed. With low powers this condensation appears considerably like a star, but high powers disperse it and leave only a very faint stellar nucleus.

Its spectrum has been investigated as thoroughly as the Lick apparatus would permit, though the chromatic aberration of the 36-inch lenses prevented me from carrying the work far into the ultra-violet. The visual observations were made mostly in September and October, 1893, and the photographic in September and October, 1892, and in June and July, 1893.

Visually, I was able to observe the lines Hα, $D_3$, 575, 541, 518, 501, 496, Hβ, 471, 469, 464, 447, 436, Hγ, Hδ; or fifteen in all. Lists of the lines shown on five negatives are given in the following columns, beginning with λ5007. All the lines preceding λ 5007 were measured visually. The relative intensities of the three principal lines are about as 5:2:1.

Table V.—Bright Lines Observed in G. C. 4390.

| | | | | | |
|---|---|---|---|---|---|
| | | | | 6563 | Hα, extremely faint. |
| 5877 | 5873 | 5877 | | | $D_3$, faint. |
| | | | 5754 | 5751 | Very faint. |
| | | | 5414 | 5412 | Extremely faint. |
| | | | 5186 | 5185 | Very faint. |
| 5007 | 5007 | 5007 | 5007 | 5007 | 1st nebular line, very bright |
| 4959 | 4959 | 4959 | 4959 | 4959 | 2d " " " " |
| 4861 | 4861 | 4861 | 4861 | 4861 | Hβ, very bright. |
| | | 4744 | 4743 | | Faint. |
| 472 | 4716 | 4714 | 4712 | | " |
| 4687 | 4686 | 4687 | 4687 | | " |
| | | | 4663 | | Very faint. |
| 4639 | 4645 | 4645 | 4643 | | Faint. |
| | | | 461 | | Very faint, somewhat uncertain. |
| | | 460 | 459 | | Very faint. |

* A. and A.-P., for January, 1893, pp. 52, 55.

| | | | | | |
|---|---|---|---|---|---|
| | | | 4574 | | Faint. |
| 4473 | 4473 | 4473 | 4473 | 4473 | Very bright. |
| 4390 | 4390 | 4390 | 4390 | | Faint. |
| 4365 | 4364 | 4364 | 4364 | 4363 | Bright. |
| 4341 | 4341 | 4341 | 4341 | 4341 | H$\gamma$, very bright. |
| | | | | 4265 | Very faint. |
| | | | | 4145 | " " |
| | | | | 4122 | " " |
| | 4102 | 4102 | | 4102 | H$\delta$, very bright. |
| | | | | 4067 | Very faint. |
| | | | | 4026 | " " |
| | | 3969 | | 3969 | H$\varepsilon$, bright. |
| | | | | 3889 | H$\zeta$, faint. |
| | | | | 3868 | Bright. |

Of these twenty-nine bright lines, eighteen at least appear to be new. The lines at $\lambda$ 5007, $\lambda$ 4959, $\lambda$ 4861 were among the first nebular lines discovered by Dr. Huggins, in 1864. Professor Vogel observed the line $\lambda$ 518 in 1871. Dr. Keeler, in 1890, detected other bright lines H$\alpha$, $D_3$, H$\gamma$, and three others placed by eye-estimates at about $\lambda$ 5680, $\lambda$ 5400 and $\lambda$ 4450. It is probable that the last three are identical with the lines observed by me at 575, 541 and 447.

The line $D_3$ is sufficiently bright for its form to be observed. When it is in focus, it does not reduce to a point: it extends out a perceptible distance from the continuous spectrum of the nucleus; and, as is the case with the principal visual lines, belongs to the nebula proper. The continuous spectrum is quite strong; but how much of it is due to the nebula and how much to the stellar nucleus cannot be said, as they are superposed.

It is nearly certain that a very faint line exists in this nebula at $\lambda$ 4924.

### The Ring Nebula in Lyra, G. C. 4447.

In addition to the three well-known bright lines at $\lambda$ 501, $\lambda$ 496, $\lambda$ 486 already observed in this nebula, there is a fourth bright line at $\lambda$ 469. The fourth line is relatively as bright in this nebula as it is in N. G. C. 7027 and G. C. 4964, and these three spectra are probably essentially identical. The relative visual intensities of the four lines in the ring nebula were estimated at

$$10(+) : 3 : 1(-) : \tfrac{1}{3}.$$

The third line H$\beta$ appears to be relatively fainter than in the other nebulæ.

The continuous spectrum is visible from $\lambda$ 55 to $\lambda$ 46. The spectrum of the central star could not be seen. No photographs were secured.

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Von Gothard, in September 1892, photographed lines at 434, 411, 3965, 3865, 373, none of which had been previously observed.

### The Planetary Nebula, N. G. C. 7027.

This object contains two nuclei of nebulous matter, in which there are apparently no stars. One of the nuclei is especially bright and condensed. In the spectrum of the principal nucleus I was able to observe, visually, the bright lines H$\alpha$, $D_3$, 575, 541, 531, 518, 501, 496, H$\beta$, 474, 472, 469, 463, H$\gamma$, H$\delta$. The condensed parts of the nebula give a fairly bright continuous spectrum. The relative intensities of the four principal lines, 5007, 4959, 4861, 4688, were estimated at

$$10 : 3 : 1 : \tfrac{1}{2}.$$

I have not been able to complete the photographic investigation of this spectrum. The first column below contains the wavelengths of the bright lines obtained by a short exposure in September, 1892. The results in the last three columns were obtained visually in 1893.

Table VI.—Bright Lines Observed in N. G. C. 7027.

| | | | | |
|---|---|---|---|---|
| | | | 6562 | H$\alpha$, extremely faint. |
| | | | 5877 | $D_3$, very faint. |
| | 5752 | 5750 | 5753 | Very faint. |
| | 5412 | 5413 | 5412 | Faint. |
| | 533 | | 5313 | Very faint. |
| | | 5178 | 5186 | " " |
| 5007 | | | | 1st nebular line, very bright. |
| 4959 | | | | 2d nebular line, very bright. |
| 4861 | | | | H$\beta$, very bright. |
| 4741 | 4745 | | | Bright. |
| 4716 | 4716 | | | Faint. |
| 4688 | 4688 | 4688 | | Very bright. |
| | 463 | | | Faint, very difficult visually. |
| 4363 | | | | Bright. |
| 4341 | | | | H$\gamma$, very bright. |
| 4102 | | | | H$\delta$, " " |

Nine of these sixteen lines appear to be new. Lines observed by Dr. Keeler in 1890 which he placed, by eye-estimates, at about $D_3$, $\lambda$ 5400, $\lambda$ 5200, $\lambda$ 4700, were doubtless the lines in Table VI, at $D_3$, 5412, 5182, 4688. Additional lines were photographed by Gothard in Oct. 1892 at $\lambda$ 395, $\lambda$ 3857.

### The Planetary Nebula, G. C. 4964.

This nebula consists of two nearly concentric rings more or less broken up, with a 14 ± magnitude stellar nucleus near its center. No part of the nebula is especially dense. The spectrum of the central star is too faint to be seen, but the nebula, with wide slit, gives a fairly strong continuous spectrum.

Visually, I am able to see in this spectrum the bright lines 541, 532, 501, 496, H$\beta$, 474, 469, H$\gamma$. The relative intensities of the four principal lines, 5007, 4959, 4861, and 4687 were estimated at 10 : 3 : 1 : ½.

A list of the measured wave-lengths of the bright lines follows. Those in the first column were made visually; those in the last two columns, photographically in 1893.

Table VII.—Bright Lines Observed in G. C. 4964.

| | | | |
|---|---|---|---|
| 540 | | | Very faint, difficult. |
| 532 | | | " " " |
| | 5007 | 5007 | 1st nebular line, very bright. |
| | 4959 | 4959 | 2d " " " " |
| | 4861 | 4861 | H$\beta$, very bright. |
| | 4744 | 4744 | Faint. |
| | 4715 | 4713 | " |
| 4684 | 4687 | 4688 | Very bright. |
| | 466 | 4663 | Very faint. |
| | 4643 | 4647 | Faint. |
| | 4473 | 4472 | Very faint. |
| | 4364 | 4364 | Bright. |
| | 4341 | 4341 | H$\gamma$, very bright. |
| | 4102 | 4102 | H$\delta$, " " |
| | | 4067 | Very faint. |
| | | 4026 | " " |
| | | 3969 | H$\varepsilon$, very bright. |
| | | 3868 | Very bright. |

Of these eighteen lines, Dr. Huggins in 1864 observed those at 5007, 4959, 4861, 4688; Keeler added H$\gamma$ in 1890; Gothard in 1892 photographed additional lines at 409, 397, 3865; and ten of the lines appear to be new.

The wave-lengths of the thirty-six bright lines in the seven nebulæ observed are collected in Table VIII. The visual spectra have been observed qualitatively as completely as possible. The photographic investigations have been made as complete as possible for the Orion Nebula, G. C. 4373, G. C. 4390 and G. C. 4964. It is evident, however, that a reflecting telescope or a photographic telescope would have been much more efficient in the violet end of the spectrum.

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TABLE VIII.—BRIGHT LINES OBSERVED IN THE NEBULÆ.

| Orion Nebula | *SDM −12°1172 | G. C. 4373 | G. C. 4390 | *G. C. 4447 | †N.G.C. 7027 | G. C. 4964 |
|---|---|---|---|---|---|---|
| | Hα | 6560 | 6563 | | 6562 | |
| 5874 | | 5879 | 5876 | | 5877 | |
| | | 5750 | 5752 | | 5752 | |
| | | | 5413 | | 5412 | 540 |
| | | | | | 5313 | 532 |
| | | | 5185 | | 5182 | |
| 5007 | 5007 | 5007 | 5007 | 5007 | 5007 | 5007 |
| 4959 | 4959 | 4959 | 4959 | 4959 | 4959 | 4959 |
| 4861 | 4861 | 4861 | 4861 | 4861 | 4861 | 4861 |
| | | | 4743 | | 4743 | 4744 |
| 4714 | | 4716 | 4714 | | 4716 | 4714 |
| | | 4688 | 4687 | 469 | 4688 | 4686 |
| 4662 | | | 4663 | | | 4663 |
| | | 464 | 4643 | | 463 | 4645 |
| | | | 461 | | | |
| | | | 459 | | | |
| | | | 4574 | | | |
| 4472 | | 4472 | 4473 | | | 4472 |
| 4389 | | | 4390 | | | |
| 4364 | | 4363 | 4364 | | 4363 | 4364 |
| 4341 | Hγ | 4341 | 4341 | | 4341 | 4341 |
| 4265 | | | 4265 | | | |
| 423 | | | | | | |
| 4143 | | | 4145 | | | |
| 4121 | | | 4122 | | | |
| 4102 | Hδ | 4102 | 4102 | | 4102 | 4102 |
| 4067 | | 4067 | 4067 | | | 4067 |
| 4026 | | 4026 | 4026 | | | 4026 |
| 3969 | | 3969 | 3969 | | | 3969 |
| 3889 | | 3888 | 3889 | | | |
| 3869 | | 3867 | 3868 | | | 3868 |
| 3835 | | | | | | |
| 3798 | | | | | | |
| 3770 | | | | | | |
| 3749 | | | | | | |
| 3727 | | | | | | |

The prevalence of the same lines in these nebulæ is very noticeable; but it would probably be found to be much more general if the nebulæ were more nearly of the same density, so that equivalent exposures could be made. The relative intensities of the lines, however, vary considerably in the different nebulæ. The absence of the line λ 4687, and to a less extent λ 464, from the Orion Nebula is conspicuous. The faintness of λ 4472 in N. G. C. 7027 and G. C. 4964 is also very noticeable, as also is the brightness of λ 4687 in the same nebulæ. The hydrogen lines are, of course, prominent in all the spectra. The line at λ 5751 is prom-

* No photographs taken.
† Photographic investigation not as complete as possible.

nent in the present spectrum of Nova Aurigæ, and possibly of Nova Normæ. The faint line near λ 5313 is possibly the coronal" line at λ 5317.

There are a few points of correspondence between the nebular spectrum and that of the Wolf-Rayet stars, notably at $D_3$, λ 5412, λ 4687, λ 4472, λ 4389, and the hydrogen lines; but there are so many points where correspondence is lacking, that we cannot say the two types are closely related. However, this subject will be discussed in detail in another paper soon to be published.

The close connection of the nebular spectrum and that of the Orion stars was brought out in Table III. That table, constructed especially for the Orion Nebula, will serve equally well for the other nebulæ, and need not be reproduced here.

No evidence has been obtained to show that any of the stellar nuclei of the nebulæ contain bright lines, and no dark lines have been observable in them. The faint bright lines probably belong entirely to the nebulæ proper. It is possible, however, that some of the faint lines obtained photographically are due to the light of the stellar nuclei; but a comparison of the lines obtained in nebulæ *with* and *without* stellar nuclei shows that such an assumption is unnecessary. Nevertheless, the connection of the planetary nebulæ and their stellar nuclei is undoubtedly a close one. The relation of their spectra should be investigated as far as possible. Certainly, at no other point in astro-physical research is accurate knowledge more desirable. The Lick Observatory does not as yet possess suitable apparatus for the work.

I wish to acknowledge having received valuable assistance in making the above observations from Mr. C. D. Perrine, Secretary of the Observatory; from Mr. S. D. Townley, now Instructor in Astronomy in the University of Michigan; and especially from Assistant Astronomer A. L. Colton: without which many of the results would be much less complete.*

LICK OBSERVATORY, 1894, March 20.

## STARS HAVING PECULIAR SPECTRA.†

M. FLEMING.

An examination of photographs of stellar spectra, taken at the Peruvian station of Harvard College Observatory under the

* CORRECTION: My statement in regard to the dark $D_3$ in β and ε Orionis, on page 395, line + 7, of the May A AND A.-P. requires modification. It is true of stars containing only dark lines, so far as I know. The dark component of the $D_3$ line in β Lyræ is of course well known.—Mt. Hamilton, 1894, May 7.

† Communicated by Edward C. Pickering Director of Harvard College Observatory.

direction of Professor S. I. Bailey, and forming part of the work of the Henry Draper Memorial, has added several faint objects to the list of stars having peculiar spectra. The designation of the star is followed by its approximate right ascension and declination for 1900, its catalogue magnitude and a brief description of its photographic spectrum.

| Designation. | R. A. 1900 h m | Decl. 1900 ° ′ | Magn. | Description. |
|---|---|---|---|---|
| BD. + 30° 591 | 3 49.1 | + 30 46 | 6.5 | Hβ bright |
| A.G.C. 13539 | 9 51.3 | − 41 7 | 7½ | Type IV |
| A.G.C. 19254 | 14 7.4 | − 53 28 | 7½ | Type IV |
| ..... | 16 24.7 | − 40 2 | ... | Gaseous Nebula. |
| S.D. − 21° 4 | 16 55.6 | − 21 40 | 9 5 | Gaseous Nebula. |
| Z.C. 17h 2657 | 17 40.8 | − 35 40 | 8 | Type IV |
| A.G.C. 24406 | 17 52.7 | − 36 0 | 7.2 | Hβ bright. |
| S.D. − 15° 4923 | 18 13.6 | − 15 39 | 9.0 | Type IV |
| S.D. − 13° 5083 | 18 38.7 | − 13 20 | 9.1 | Type V |
| BD. + 11° 4673 | 21 46.2 | + 12 9 | 7.7 | Hβ bright. |

BD. + 30° 591. The spectrum of this star also shows a bright line superposed on the edge of shorter wave-length of the line Hγ which is dark.

S.D. — 21° 4483. An observation of this object on May 10, 1894, with the 15-inch equatorial, by Mr. O. C. Wendell, confirms the photographic results. Its visual spectrum is the same as that of other gaseous nebulæ and it presents a hazy disk when seen with a high power.

A.G.C. 24406. The spectrum of this star shows a bright line superposed on the edge of greater wave-length of each of the lines Hγ and Hδ, which are dark.

S.D. — 13° 5083. This star like all others of the same class lies near the central line of the Milky Way, its Galactic longitude being 348° 1′ and its Galactic latitude — 5° 55′.

BD. + 11° 4673. The spectrum of this star shows the lines Hγ and Hδ also bright.

*New Variable Stars.* Three new variable stars have also been discovered in this examination by means of the presence of bright hydrogen lines in their photographic spectra. In the table the constellation is followed by the approximate right ascension and declination for 1900, the magnitude when brightest and when faintest, as derived from the photographs at present at the Observatory, and the number of plates examined.

| Constell. | R. A. 1900 h m | Decl. 1900 ° ′ | Photog. Br. | Magn. Ft. | No. Plates |
|---|---|---|---|---|---|
| Carina | 9 54.8 | − 58 23 | 8.2 | 9.6 | 24 |
| Carina | 10 10.4 | − 58 21 | 9.4 | 12.1 | 18 |
| Centaurus | 12 28.0 | − 54 6 | 9.2 | 11.3 | 16 |

The first of these stars is A. G. C. 13624, Magn. 8.

It must be here understood that the stars in the above table are not here announced as "suspected" variables since each of them appears bright on several plates and faint on several other plates. The variation has also been confirmed in each case by Professor E. C. Pickering. This is also the case with all the variable stars discovered here from the presence of bright hydrogen lines in their photographic spectra, with the exception of the star whose position for 1900 is in R. A. $15^h\ 27.0^m$, Decl. $-71°\ 32'$. (ASTRONOMY AND ASTRO-PHYSICS Vol. XII, p. 546).

Photographs of the spectra of the variable stars S Orionis, U Puppis, V Leonis, S Boötis, and R Phoenicis have been examined and show bright hydrogen lines. S Orionis and S Boötis were obtained from an examination of photographs taken with the 24-inch Bruce photographic telescope.

HARVARD COLLEGE OBSERVATORY,
Cambridge Mass., May 11, 1894.

## SOLAR PHENOMENA OBSERVED AT THE ROYAL ROMAN COLLEGE DURING THE THIRD AND FOURTH QUARTERS OF THE YEAR 1893.*

P. TACCHINI.

I give below a résumé of the results which I have obtained for the distribution in latitude of solar phenomena, from observations made at the Royal Roman College during the latter half of the year 1893. The observations refer to zones 10° wide in each hemisphere of the Sun.

| 1893. | Perturbations. | | Faculæ. | | Spots. | |
|---|---|---|---|---|---|---|
| Latitude. | 3rd Quarter. | 4th Quarter. | 3rd. Quarter. | 4th Quarter. | 3rd Quarter. | 4th Quarter. |
| ° ° | | | | | | |
| 90 + 80 | 0.000 | 0.000 | | | | |
| 80 + 70 | 0.011 | 0.000 | | | | |
| 70 + 60 | 0.011 | 0.000 | | | | |
| 60 + 50 | 0.011 | 0.011 | | | | |
| 50 + 40 | 0.042 0.426 | 0.016 0.394 | 0.000 | 0.000 | 0.006 | 0.000 |
| 40 + 30 | 0.111 | 0.069 | 0.017 | 0.020 | 0.006 | 0.070 |
| 30 + 20 | 0.105 | 0.149 | 0.068 0.442. | 0.106 0.463 | 0.061 0.400 | 0.070 0.421 |
| 20 + 10 | 0.069 | 0.091 | 0.184 | 0.192 | 0.200 | 0.219 |
| 10 + 0 | 0.066 | 0.058 | 0.173 | 0.145 | 0.127 | 0.132 |
| 0 — 10 | 0.057 | 0.061 | 0.109 | 0.184 | 0.127 | 0.228 |
| 10 — 20 | 0.076 | 0 066 | 0.177 | 0.208 | 0.279 | 0.237 |
| 20 — 30 | 0.107 | 0.121 | 0 184 0.558 | 0.106 0.537 | 0.176 0.600 | 0.105 0.579 |
| 30 — 40 | 0.081 | 0.088 | 0.085 | 0.031 | 0.018 | 0.009 |
| 40 — 50 | 0.021 0.574 | 0.028 0.606 | 0.003 | 0.008 | 0.000 | |
| 50 — 60 | 0.110 | 0.063 | | | | |
| 60 — 70 | 0.115 | 0.168 | | | | |
| 70 — 80 | 0.007 | 0.011 | | | | |
| 80 — 90 | 0.000 | 0.000 | | | | |

* Communicated by the author.

As in the preceding half year, all the phenomena have been more frequent in the southern zones, but it should be noted that the frequency of the faculæ and spots was almost the same in the two hemispheres during the months of November and December. The maximum frequency of the faculæ and the spots continued to be in the zones ($\pm 10° \pm 20°$) while that of the protuberances was found in higher latitudes. The persistence of the maximum of the protuberances in latitude ($-50° - 70°$), which had already been observed in the second quarter of the year, and which was preceded by a well-marked minimum in the zone ($-40° - 50°$), is very irregular. The greater activity in the southern hemisphere is further confirmed by the fact that the highest and most beautiful protuberances have almost always been observed south of the solar eqator, thus demonstrating that outside of the solar rotation there are causes still unknown which produce a marked variation of the solar activity with the latitude and with the hemisphere.

During the third quarter we observed no metallic eruptions, and during the fourth quarter we found indications of eruption on December 25 and 26 only, in latitude $+ 21°.7$ and $+ 22°.6$ on the east limb. The photographs which we have obtained also show a greater activity south of the solar equator.

## ASTRO-PHYSICAL NOTES.

All articles and correspondence relating to spectroscopy and other subjects, properly included in ASTRO-PHYSICS, should be addressed to George E. Hale, Kenwood Observatory of the University of Chicago, Chicago, U. S. A. Authors of papers are requested to refer to last page for information in regard to illustrations, reprint copies, etc.

**The Spectrum of Comet *b*, 1894 (Gale).**—The spectrum of Gale's comet was observed at Allegheny on April 9, and appeared to be of the ordinary carbon type; no photographs of the spectrum were attempted. At Mt. Hamilton Professor Campbell obtained some fine photographs, showing more than twenty lines. The spectrum was identical with that of Comet *b*, 1893.

**Red Fringe to the Orion Nebula.**—Professor Barnard describes in *Knowledge*, (May 1) a red fringe of light which he sees around the sharply defined southern edge of the great bright area in the Nebula of Orion. He is not prepared to say what the phenomenon is, but hardly thinks that it is a telescopic effect.

As the Nebula of Orion emits no red light, there is no doubt that the appearance is subjective, arising from the effect on the retina of the bluish-green light of the bright region to which reference is made. The production of these colored subjective images is a common experiment in physiological optics.

**The Influence of Slit-Width on the Appearance of Comet-Spectra.**—Professor Vogel contributes on article to *A. N.* 3222, in which he shows that in 1881 he had already called special attention to the influence of slit-with on the distribution of light in the bands of comet-spectra. In a monograph on the great comet of 1881, published by the Potsdam Observatory, Professor Vogel makes the following remarks:

"I do not wish to bring these considerations to an end without calling attention to the fact that the width of the slit of the spectroscope is capable of producing a very great effect on the *distribution* of light in bands which are diffuse on one side, while lines, or bands diffuse on both sides, are almost entirely unaffected by it. How great the influence of the slit width may be, is shown by the following observations; and I should recommend all observers not to overlook this circumstance but in all measurments and records of the relative intensities to assure themselves that the slit is made as narrow as possible. There is no doubt that the greatly discordant observations of faint comets have their origin in the very wide slit which was necessary in order that the faint bands of their spectra could be seen at all."

The observations referred to by Professor Vogel in the beginning of this paragraph were made with different slit-widths, the source of light being a Bunsen-flame placed at different distances from the instrument. They show the progressive shifting of the maximum brightness toward the violet as the slit-width is increased.

Professor Vogel still thinks that varying slit-width is not a sufficient expalanation of the observed deviation of certain comet-spectra from the ordinary carbon type, and regards the coexistence of the CO spectrum in these cases as altogether probable.

Notwithstanding this previous discussion of the subject, the paper by Professor Kayser, translated in our last number, is of very great value, on account of its admirable clearness and thoroughness. Whether it explains all observed anomalies in comet-spectra, or whether, as Professor Vogel maintains, some of these anomalies have their origin in real differences of spectra, future observations with the aid of photography will probably decide. It can hardly be supposed that exceptional cases will be rarer in the future than they have been in the past.

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**Professor Kayser at Bonn.**—Professor Heinrich Kayser of Hanover has been appointed Professor of Physics in the University of Bonn. The appointment to a chair which has been occupied by such intellectual giants as Clausius and Hertz is an honor which requires no comment, but it is one which Professor Kayser has well earned.

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**The Line Spectrum of Oxygen.**—In *Wied. Ann.*, 4, 1894, there is an interesting article by Max Eisig, which gives the results of his measurements of the line spectrum of oxygen. The work was carried on in the laboratory of Kayser and Runge at Hanover; and their concave grating apparatus was used for the purpose. The oxygen was electolytically prepared from purified water, and was admitted to the spectrum tube after being dried over phosphoric acid. The discharge tube itself was an 'end-on" one, which had one end closed by a quartz plate fastened by water-glass. The connections of the various parts to the mercury pump were made by sealing-wax joints, and grease was used with the stop-cock; but in spite of these facts no impurity-lines appeared in the spectra, probably owing to the

fact that repeated refilling with oxygen removes the ordinary carbon impurities. The vacuum used was not very great, although various pressures and e. m. f's. were used; and so, although traces of water-vapor were always present, they produced little or no effect on the photographic plates. The grating was a concave one, 21 feet radius and having 20,000 lines to the inch; and photographs were taken throughout the entire spectrum as far as the plates would allow. Exposures of from 2½ to 4 hours were found necessary. On the same plates and directly over the oxygen lines, was photographed the arc-spectrum of iron, care being taken to avoid displacement; and then comparisons of the two spectra were made under a dividing engine. The measurements of the oxygen lines are thus reduced to the same scale as Kayser and Runge's wave-lengths, *i. e.*, one where the standards are $D_1 = 5896.16$ and $D_2 = 5890.19$ (Rowland's standards are $D_1 = 5896.156$ and $D_2 = 5890.182$) Eisig estimates his probable error at from 0.1 to 0.2 Angstrom unit. Of course in a spectrum so imperfectly studied in the past as that of oxygen, it is impossible to be sure that all the lines observed belong to the substance itself; but the cases of doubtful lines are rare. There is no grouping of the lines in series, as there is in the case of hydrogen and other substances; and careful examination shows that none of the lines measured occur in the solar spectrum. This is no evidence, of course, that oxygen is not present in the Sun. It may be there, and its spectrum may be too weak for observation; or the conditions under which it exists may be such that a different spectrum from the so-called "line-spectrum" is produced.

The lines measured by Eisig and attributed to oxygen have the following wave-lengths and intensities:

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2433.6 | 5 | 3410.2 | 5 | 3912.3 | 3 | 4096.9 | 6 | 4144.0 | 6 | 4332.2 | 6 | 4448.7 | 6 | 4662.0 | 4 |
| 2445.6 | 4 | 3712.8 | 4 | 3919.6 | 4 | 4097.8 | 6 | 4146.3 | 5 | 4337.3 | 4 | 4452.8 | 5 | 4674.2 | 6 |
| 2478.8 | 3 | 3727.5 | 3 | 3945.3 | 4 | 4103.4 | 6 | 4153.7 | 3 | 4345.9 | 2 | 4465.8 | 6 | 4676.6 | 5 |
| 2512.3 | 5 | 3749.6 | 2 | 3954.5 | 3 | 4105.3 | 4 | 4156.8 | 6 | 4347.8 | 3 | 4466.7 | 6 | 4696.8 | 4 |
| 3134.9 | 5 | 3754.7 | 6 | 3973.4 | 1 | 4111.2 | 6 | 4169.5 | 6 | 4349.8 | 1 | 4468.4 | 6 | 4699.6 | 6 |
| 3138.6 | 6 | 3757.3 | 6 | 3983.0 | 4 | 4112.4 | 5 | 4185.8 | 4 | 4351.7 | 2 | 4469.9 | 6 | 4701.5 | 6 |
| 3271.2 | 6 | 3760.0 | 6 | 4070.1 | 1 | 4114.2 | 6 | 4190.0 | 4 | 4367.3 | 3 | 4591.4 | 3 | 4703.4 | 6 |
| 3273.9 | 6 | 3851.2 | 6 | 4072.5 | 1 | 4119.5 | 2 | 4317.4 | 3 | 4369.7 | 6 | 4596.5 | 4 | 4705.7 | 4 |
| 3287.8 | 6 | 3857.4 | 6 | 4076.2 | 1 | 4120.5 | 4 | 4319.9 | 3 | 4396.4 | 5 | 4639.2 | 4 | 4710.4 | 5 |
| 3377.1 | 4 | 3864.8 | 5 | 4079.1 | 5 | 4121.7 | 6 | 4326.2 | 6 | 4415.3 | 1 | 4642.1 | 2 | | |
| 3390.2 | 3 | 3882.5 | 3 | 4085.5 | 4 | 4133.2 | 5 | 4327.8 | 6 | 4417.4 | 2 | 4649.5 | 1 | | |
| 3407.7 | 5 | 3907.6 | 6 | 4093.2 | 5 | 4142.4 | 6 | 4329.0 | 6 | 4443.6 | 6 | 4651.2 | 4 | | |

J. S. A.

**Height of Auroræ.**—Mr. W. H. Wood, of Birmingham, England, wrote recently to the secretary of the Astronomical and Physical Society of Toronto, Canada, objecting to the calculated height of the aurora of July 15th, 1893, as demonstrated in that society's latest annual report. Mr. Wood held that such calculations were impossible. Mr. Arthur Harvey, of the Astronomical and Physical Society of Toronto differed from the conclusions of Mr. Wood, explained the method by which the height of the auroral arch of July 15th had been calculated and referred to correspondence from Dr. M. A. Veeder of Lyons, N. Y., to show that the mode was being usefully employed elsewhere than in Toronto. Dr. Veeder stated that auroral research is progressing, reports arriving from Siberia, Finland, Scandinavia, Alaska and other distant places; also that the observations in connection with the display of March 30th were the best of which he had any knowledge for the determination of altitude. It had been satisfactorily established that at 8 o'clock P. M., the apex of the luminous mass, so well seen above Toronto at that hour, was from 300 to 350 miles above the surface of the Earth.

JOHN A. COPLAND.

**Errata in April No. of A. and A. P.**—Page 280, line 15, for "curve" read "cause." Page 280, line 17, for "black" read "white." Page 281, line 24, strike out eleventh word "of." Page 281, line 34, for "expression" read "expansion." Page 282, line 5, for "standard" read "retarded." Page 307, last line, for 1893 read 1894.

# CURRENT CELESTIAL PHENOMENA.

## PLANET NOTES FOR JULY AND AUGUST.

H. C. WILSON.

*Mercury*, having been visible in the evening during the last days in June, will in July pass between us and the Sun, being hidden by the rays of the latter during the greater part of the month. He will be at inferior conjunction July 20 at $4^h$ $28^m$ P. M. central time.

*Venus* is slowly receding from us and moving around behind the Sun. Her disc will be 0.76 illuminated July 1 and 0.92 August 30. Venus will pass by Jupiter on the morning of July 20, the nearest approach of the two planets to each other occurring at about $2^h$ $30^m$ A. M. On the morning of July 28 at $6^h$ $13^m$ Venus will pass very close to the third magnitude star $\mu$ Geminorum, the difference of declination of the two bodies at the time of conjunction being only 3′. August 8 at $7^h$ $45^m$ A. M. Venus will pass 9′ to the south of another third magnitude star, $\delta$ Geminorum. Venus will be in conjunction with the Moon July 30 at $1^h$ $34^m$ A. M. and August 28 at $7^h$ $23^m$ P. M.

*Mars* will come into good position for observations after midnight by the first of August, and it is to be hoped that observers will begin early to study the markings on the surface of the planet. It is not necessary to have a great telescope, in order to see them to good advantage In fact there are some good observers who believe that planetary details can be seen better with small than with large telescopes. We do not subscribe to this belief, but do say that the difference in favor of the large telescope is not so great as to entirely discourage the possessor of a good small one from attempting to add to our knowledge of the planetary markings.

*Jupiter* and *Neptune* are coming around as morning planets but will not be in good position for observation during the summer. As already noted, Jupiter will be in conjunction with Venus, 51′ north of the latter, on the morning of July 20. Neptune will be still closer to Venus, only 9′ north, July 11, $11^h$ $54^m$ P. M.

*Saturn* will be visible in the early evening but will be pretty low in the west by the time twilight is over. Saturn and the Moon will be in conjunction July 9 at $9^h$ $11^m$ P. M. and August 6, $7^h$ $30^m$ A. M.

*Uranus* is making the turn of the loop in his apparent course among the stars and will be almost stationary during July. In August he will move eastward toward the star $\alpha$ Libræ. Uranus will be in conjunction with the Moon July 11 and August 7.

### Planet Tables for July and August.

[The times given are local time for Northfield. To obtain Standard Times for Places in approximately the same latitude, add the difference between Standard and Local Time if west of the Standard Meridian or subtract if east].

MERCURY.

| Date. 1894. | R. A. h m | Decl. ° ′ | Rises. h m | Transits h m | Sets. h m. |
|---|---|---|---|---|---|
| July 5..... | 8 23.4 | +16 59 | 6 16 A. M. | 1 28.2 P. M. | 8 41 P. M. |
| 15..... | 8 11.0 | +15 25 | 5 30 " | 12 36.5 " | 7 43 " |
| 25..... | 7 44 8 | +16 30 | 4 18 " | 11 31.2 A. M. | 6 42 " |
| Aug. 5..... | 7 46.0 | +18 53 | 3 27 " | 10 49.2 " | 6 11 " |
| 15..... | 8 33.0 | +19 04 | 3 33 " | 10 56.7 " | 6 02 " |
| 25..... | 9 47.4 | +15 04 | 4 27 " | 11 31.5 " | 6 36 " |

VENUS.

| Date. | R. A. h m | Decl. ° ′ | Rises. h m | Transits. h m | Sets. h m |
|---|---|---|---|---|---|
| July 5..... | 4 21.5 | +19 39 | 2 01 A. M. | 9 27.0 A. M. | 4 53 A. M. |
| 15..... | 5 11.0 | +21 30 | 2 02 " | 9 37.0 " | 5 12 " |
| 25..... | 6 01.9 | +22 26 | 2 09 " | 9 48.4 " | 5 28 " |
| Aug. 5..... | 6 58.8 | +22 17 | 2 23 " | 10 02.0 " | 5 41 " |
| 15..... | 7 50.4 | +21 02 | 2 41 " | 10 14.1 " | 5 47 " |
| 25..... | 8 41.2 | +18 47 | 3 04 " | 10 25.5 " | 5 47 " |

MARS.

| | | | | | |
|---|---|---|---|---|---|
| July 5..... | 0 35.0 | + 0 27 | 11 32 P. M. | 5 37.2 A. M. | 11 42 A. M. |
| 15..... | 0 56.8 | + 2 34 | 11 06 " | 5 19.5 " | 11 33 " |
| 25..... | 1 17.1 | + 4 28 | 10 40 " | 5 00.6 " | 11 21 " |
| Aug. 5..... | 1 37.2 | + 6 18 | 10 09 " | 4 37.4 " | 11 06 " |
| 15..... | 1 52.8 | + 7 40 | 9 40 " | 4 13.6 " | 10 47 " |
| 25..... | 2 05.1 | + 8 44 | 9 08 " | 3 46.6 " | 10 25 " |

JUPITER.

| | | | | | |
|---|---|---|---|---|---|
| July 5..... | 5 20.9 | +22 43 | 2 45 A. M. | 10 26.2 A. M. | 6 07 P. M. |
| 15..... | 5 30.4 | +22 52 | 2 15 " | 9 56.4 " | 5 38 " |
| 25..... | 5 39.5 | +22 58 | 1 44 " | 9 26.2 " | 5 08 " |
| Aug. 5..... | 5 49.1 | +23 02 | 1 10 " | 8 52.4 " | 4 35 " |
| 15..... | 5 57.0 | +23 04 | 12 38 " | 8 21.1 " | 4 04 " |
| 25..... | 6 04.4 | +23 04 | 12 06 " | 7 49.2 " | 3 32 " |

SATURN.

| | | | | | |
|---|---|---|---|---|---|
| July 5.....13 | 12.5 | − 4 57 | 12 33 P. M. | 6 16.5 P. M. | 12 00midn |
| 15.....13 | 13.6 | − 5 07 | 11 55 A. M. | 5 38.3 " | 11 22 P. M. |
| 25.....13 | 15.3 | − 5 20 | 11 18 " | 5 00.8 " | 10 43 " |
| Aug. 5.....13 | 17.8 | − 5 37 | 10 39 " | 4 20.0 " | 10 01 " |
| 15.....13 | 20.5 | − 5 57 | 10 04 " | 3 43.4 " | 9 23 " |
| 25.....13 | 23.7 | − 6 18 | 9 29 " | 3 07.3 " | 8 46 " |

URANUS.

| | | | | | |
|---|---|---|---|---|---|
| July 5.....14 | 36.2 | − 14 52 | 2 37 P. M. | 7 40.0 P. M. | 12 43 A. M. |
| 15.....14 | 35.8 | − 14 51 | 1 57 " | 7 00.4 " | 12 04 " |
| 25.....14 | 35.8 | − 14 51 | 1 18 " | 6 21.1 " | 11 24 P. M. |
| Aug. 5.....14 | 36.2 | − 14 54 | 12 35 " | 5 38.4 " | 10 41 " |
| 15.....14 | 37.0 | − 14 58 | 11 57 A. M. | 4 59.7 " | 10 02 " |
| 25.....14 | 38.0 | − 15 03 | 11 19 " | 4 21.5 " | 9 24 " |

NEPTUNE.

| | | | | | |
|---|---|---|---|---|---|
| July 5..... | 4 53.0 | +21 06 | 2 26 A. M. | 9 58.5 A. M. | 5 31 P. M |
| 15..... | 4 54.4 | +21 08 | 1 47 " | 9 20.6 " | 4 54 " |
| 25..... | 4 55.6 | +21 10 | 1 09 " | 8 42.5 " | 4 16 " |
| Aug. 5..... | 4 56.8 | +21 11 | 12 27 " | 8 00.5 " | 3 34 " |
| 15..... | 4 57.7 | +21 12 | 11 49 P. M. | 7 21.9 " | 2 55 " |
| 25..... | 4 58.4 | +21 13 | 11 10 " | 6 43.3 " | 2 17 " |

THE SUN.

| | | | | | |
|---|---|---|---|---|---|
| July 5..... | 6 59.3 | +22 45 | 4 21 A. M. | 12 04.4 P. M. | 7 48 P. M. |
| 15..... | 7 40.1 | +21 28 | 4 30 " | 12 05.7 " | 7 42 " |
| 25..... | 8 20.0 | +19 34 | 4 40 " | 12 06.3 " | 7 33 " |
| Aug. 5..... | 9 02.9 | +16 51 | 4 52 " | 12 05.8 " | 7 20 " |
| 15..... | 9 40.8 | +13 55 | 5 04 " | 12 04.2 " | 7 04 " |
| 25.....10 | 17.8 | +10 36 | 5 15 " | 12 01.9 " | 6 49 " |

THE MOON.

| | | | | | |
|---|---|---|---|---|---|
| July 1..... | 5 04.7 | +27 39 | 2 06 A. M. | 10 25.8 A. M. | 6 55 P. M. |
| 3..... | 7 28.0 | +26 49 | 4 15 " | 12 40.9 P. M. | 8 55 " |
| 5..... | 9 38.7 | +17 45 | 7 05 " | 2 43.4 " | 10 04 " |
| 7.....11 | 28.3 | + 4 43 | 9 47 " | 4 24.9 " | 10 48 " |
| 9.....13 | 06.9 | − 8 26 | 12 13 P. M. | 5 55.2 " | 11 25 " |
| 11.....14 | 45.3 | − 19 25 | 2 33 " | 7 25.6 " | 12 08 A. M. |
| 13.....16 | 30.9 | − 26 31 | 4 50 " | 9 03.0 " | 1 11 " |
| 15.....18 | 22.2 | − 28 23 | 6 47 " | 10 46.1 " | 2 46 " |
| 17.....20 | 10.8 | − 24 42 | 8 09 " | 12 26.5 A. M. | 4 50 " |
| 19.....21 | 49.9 | − 16 32 | 9 02 " | 1 57.5 " | 7 04 " |
| 21.....23 | 20.9 | − 5 34 | 9 39 " | 3 20.4 " | 9 14 " |

XUM

THE MOON.

| | Date. | R. A. | Decl. | Rises. | Transits. | Sets. |
|---|---|---|---|---|---|---|
| | | h m | ° ′ | h m | h m | h m |
| July | 23..... | 0 51.4 | + 6 36 | 10 13 P. M. | 4 42.8 A. M. | 11 27 A. M. |
| | 25..... | 2 31.6 | +18 15 | 10 53 " | 6 14.8 " | 1 53 P. M. |
| | 27..... | 4 31.7 | +26 40 | 11 55 " | 8 06.9 " | 4 30 " |
| | 30..... | 6 51.2 | +27 59 | 1 54 A. M. | 10 18.0 " | 6 49 " |
| Aug. | 1..... | 9 06.7 | +20 36 | 4 33 " | 12 25.7 P. M. | 8 01 " |
| | 3.....11 | 03.8 | + 7 47 | 7 22 " | 2 14.2 " | 8 49 " |
| | 5.....12 | 46.8 | − 6 04 | 9 56 " | 3 49.0 " | 9 29 " |
| | 7.....14 | 27.1 | −17 54 | 12 22 P. M. | 5 21.2 " | 10 11 " |
| | 9.....16 | 12.6 | −25 52 | 2 42 " | 6 58.6 " | 11 10 " |
| | 11.....18 | 03.8 | −28 36 | 4 43 " | 8 41.7 " | 12 40 A. M. |
| | 13.....19 | 53.5 | −25 42 | 6 11 " | 10 23.1 " | 2 41 " |
| | 15.....21 | 34.3 | −18 04 | 7 07 " | 11 55.9 " | 4 54 " |
| | 17.....23 | 06.8 | − 7 09 | 7 46 " | 1 20.2 A. M. | 7 07 " |
| | 19..... 0 | 36.9 | + 4 52 | 8 20 " | 2 42.2 " | 9 19 " |
| | 21..... 2 | 13.8 | +16 40 | 8 57 " | 4 11.0 " | 11 41 " |
| | 23..... 4 | 07.2 | +25 40 | 9 52 " | 5 56.3 " | 2 13 P. M. |
| | 25..... 6 | 19.6 | +28 36 | 11 29 " | 8 00.3 " | 4 29 " |
| | 28..... 8 | 34.9 | +23 11 | 2 02 A. M. | 10 07.4 " | 5 57 " |
| | 30.....10 | 35.3 | +11 18 | 4 52 " | 12 00.0 M. | 6 50 " |

## Phases and Aspects of the Moon.

*Central Time.*

| | d | h m |
|---|---|---|
| New Moon | July 2 | 11 45 P. M. |
| Perigee | " 3 | 7 40 A. M. |
| First Quarter | " 9 | 4 15 P. M. |
| Apogee | " 17 | 8 30 A. M. |
| Full Moon | " 17 | 4 03 P. M. |
| Last Quarter | " 25 | 3 07 P. M. |
| Perigee | " 31 | 5 06 P. M. |
| New Moon | Aug. 1 | 6 24 A. M. |
| First Quarter | " 8 | 4 05 A. M. |
| Apogee | " 13 | 1 30 P. M. |
| Full Moon | " 16 | 7 17 A. M. |
| Last Quarter | " 23 | 11 40 P. M. |
| Perigee | " 29 | 12 36 A. M. |
| New Moon | " 30 | 2 04 P. M. |

## Occultations Visible at Washington.

| Date 1894 | Star's Name. | Magnitude. | IMMERSION Washington M. T. | IMMERSION Angle f'm N p't. | EMERSION Washington M. T. | EMERSION Angle f't N p't. | Duration. |
|---|---|---|---|---|---|---|---|
| | | | h m | ° | h m | ° | h m |
| July 9 | 58 Virginis | 7 | 10 29 | 100 | 11 30 | 312 | 1 01 |
| 16 | B. A. C. 6628 | 6 | 12 58 | 111 | 14 00 | 209 | 1 02 |
| 18 | χ Capricorni | 5½ | 14 58 | 67 | 16 14 | 227 | 1 16 |
| 20 | B. A. C. 7835 | 6 | 7 29 | 50 | 8 24 | 270 | 0 55 |
| 23 | B. A. C. 221 | 6 | 11 34 | 15 | 12 20 | 279 | 0 46 |
| 26 | ζ Arietis | 5 | 10 14 | 67 | 11 00 | 252 | 0 46 |
| 26 | B. A. C. 1055 | 7 | 14 07 | 59 | 15 08 | 245 | 1 01 |
| 27 | χ Tauri | 6 | 13 33 | 36 | 14 16 | 284 | 0 43 |
| Aug. 13 | ω Sagittarii | 5 | 8 42 | 30 | 9 47 | 300 | 1 05 |
| 13 | A Sagittarii | 5 | 10 44 | 61 | 12 12 | 252 | 1 28 |
| 16 | 50 Aquarii | 6 | 11 25 | 60 | 12 51 | 223 | 1 26 |
| 18 | 20 Piscium | 6 | 8 14 | 29 | 9 07 | 272 | 0 53 |
| 26 | 47 Geminorum | 6 | 12 04 | 97 | 12 49 | 263 | 0 45 |

## Elongations of the Satellites of Uranus.

[The diagram shows the apparent paths of the satellites of Uranus during the summer of 1894. The black dots with the numerals indicate the positions of the satellites at intervals of 1 day after each northern elongation. The points marked 0 are those of northern elongation.]

ARIEL.

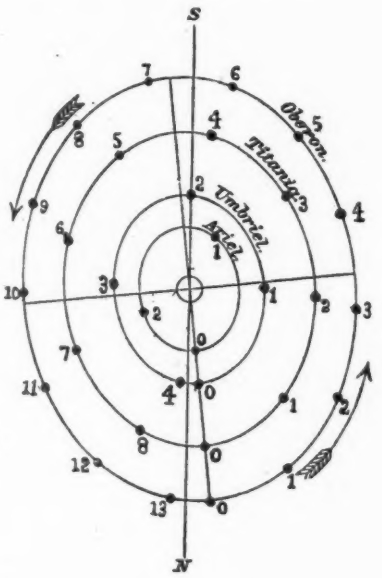
| | | h | | |
|---|---|---|---|---|
| July | 2 | 10.7 | P. M. | N |
| | 5 | 11.2 | A. M. | N |
| | 7 | 11.7 | P. M. | N |
| | 10 | 12.2 | P. M. | N |
| | 13 | 12.7 | A. M. | N |
| | 15 | 1.2 | P. M. | N |
| | 18 | 1.6 | A. M. | N |
| | 20 | 2.1 | P. M. | N |
| | 23 | 2.6 | A. M. | N |
| | 25 | 3.1 | P. M. | N |
| | 28 | 3.6 | A. M. | N |
| | 30 | 4.1 | P. M. | N |
| Aug. | 2 | 4.6 | A. M. | N |

UMBRIEL.

| | | h | | |
|---|---|---|---|---|
| July | 5 | 1.7 | A. M. | N |
| | 9 | 4.3 | " | N |
| | 13 | 7.8 | " | N |
| | 17 | 11.3 | " | N |
| | 21 | 2.8 | P. M. | N |
| | 25 | 6.3 | " | N |
| | 29 | 9.8 | " | N |
| Aug. | 3 | 1.2 | A. M. | N |

TITANIA.

| | | h | | |
|---|---|---|---|---|
| July | 2 | 6.7 | P. M. | S |
| | 7 | 3.2 | A. M. | N |
| | 11 | 11.7 | " | S |
| | 15 | 8.2 | P. M. | N |
| | 20 | 4.6 | A. M. | S |
| | 24 | 1.1 | P. M. | N |
| | 28 | 9.6 | " | S |
| Aug. | 2 | 6.1 | A. M. | N |




OBERON.

| | | h | | |
|---|---|---|---|---|
| July | 7 | 12.4 | A. M. | N |
| | 13 | 5.9 | P. M. | S |
| | 20 | 11.5 | A. M. | N |

OBERON, CONT.

| | | h | | |
|---|---|---|---|---|
| July | 27 | 5.0 | A. M. | S |
| Aug. | 3 | 10.6 | P. M. | N |

## Minima of Variable Stars of the Algol Type.

[Given to the nearest hour in Central Standard Time.]

U CEPHEI.

Alternate Minima.

| | | h | |
|---|---|---|---|
| July | 5 | 10 | P. M. |
| | 10 | 10 | " |
| | 15 | 9 | " |
| | 20 | 9 | " |
| | 25 | 9 | " |
| | 30 | 8 | " |
| Aug. | 4 | 8 | " |
| | 9 | 8 | " |
| | 14 | 7 | " |
| | 19 | 7 | " |
| | 24 | 7 | " |
| | 29 | 6 | " |

ALGOL.

Alternate Minima.

| | | h | |
|---|---|---|---|
| July | 4 | 2 | P. M. |
| | 10 | 8 | A. M. |
| | 16 | 2 | A. M. |
| | 21 | 7 | P. M. |
| | 27 | 1 | " |
| Aug. | 2 | 6 | A. M. |
| | 7 | 12 | midn. |
| | 13 | 6 | P. M. |
| | 19 | 11 | A. M. |
| | 25 | 5 | " |
| | 30 | 11 | P. M. |

λ TAURI.

Alternate Minima.

| | | h | |
|---|---|---|---|
| July | 2 | 4 | A. M. |
| | 10 | 2 | " |
| | 17 | 12 | midn. |
| | 25 | 9 | P. M. |
| Aug. | 2 | 7 | " |
| | 10 | 5 | " |
| | 18 | 2 | " |
| | 26 | 12 | M. |

δ LIBRÆ.

Alternate Minima.

| | | h | |
|---|---|---|---|
| July | 2 | 2 | P. M. |
| | 7 | 5 | A. M. |
| | 11 | 9 | P. M. |
| | 16 | 1 | " |
| | 21 | 4 | A. M. |
| | 25 | 8 | P. M. |
| | 30 | 12 | M. |
| Aug. | 4 | 4 | A. M. |
| | 8 | 7 | P. M. |
| | 13 | 11 | A. M. |
| | 18 | 3 | " |
| | 22 | 6 | P. M. |
| | 27 | 10 | A. M. |

U CORONÆ.

Alternate Minima.

| | | | |
|---|---|---|---|
| July | 2 | 9 | P. M. |
| | 9 | 7 | " |
| | 16 | 4 | " |
| | 23 | 2 | " |
| | 30 | 12 | M. |

U CORONÆ CONT.

(Alternate Minima.)

| | | h | |
|---|---|---|---|
| Aug. | 6 | 9 | A. M. |
| | 13 | 7 | " |
| | 20 | 5 | " |
| | 27 | 3 | " |

U OPHIUCHI.

(Every fourth Minimum)

| | | | |
|---|---|---|---|
| July | 1 | 4 | P. M. |
| | 5 | 1 | A. M. |
| | 8 | 9 | P. M. |
| | 11 | 6 | " |
| | 15 | 2 | A. M. |
| | 18 | 11 | " |
| | 21 | 7 | P. M. |
| | 25 | 4 | A. M. |
| | 28 | 12 | M. |
| | 31 | 9 | P. M. |
| Aug. | 4 | 6 | A. M. |
| | 7 | 2 | P. M. |
| | 10 | 11 | " |

U OPHIUCHI CONT.

(Every fourth minimum)

| | | h | |
|---|---|---|---|
| Aug. | 14 | 7 | A. M. |
| | 17 | 4 | P. M. |
| | 20 | 12 | midn. |
| | 24 | 9 | A. M. |
| | 27 | 5 | P. M. |
| | 31 | 2 | A. M. |

Y CYGNI.

(Every fourth minimum.)

| | | | |
|---|---|---|---|
| July | 6 | 11 | A. M. |
| | 12 | 10 | " |
| | 18 | 10 | " |
| | 24 | 10 | " |
| | 30 | 10 | " |
| Aug. | 5 | 10 | " |
| | 11 | 10 | " |
| | 17 | 9 | " |
| | 23 | 9 | " |
| | 29 | 9 | " |

## Maxima and Minima of Variable Stars.

[From ephemerides by Dr. Loewy in the "Companion to the Observatory," and by Dr. Hartwig in the "Vierteljahrsschrift der Astronomische Geselischaft".]

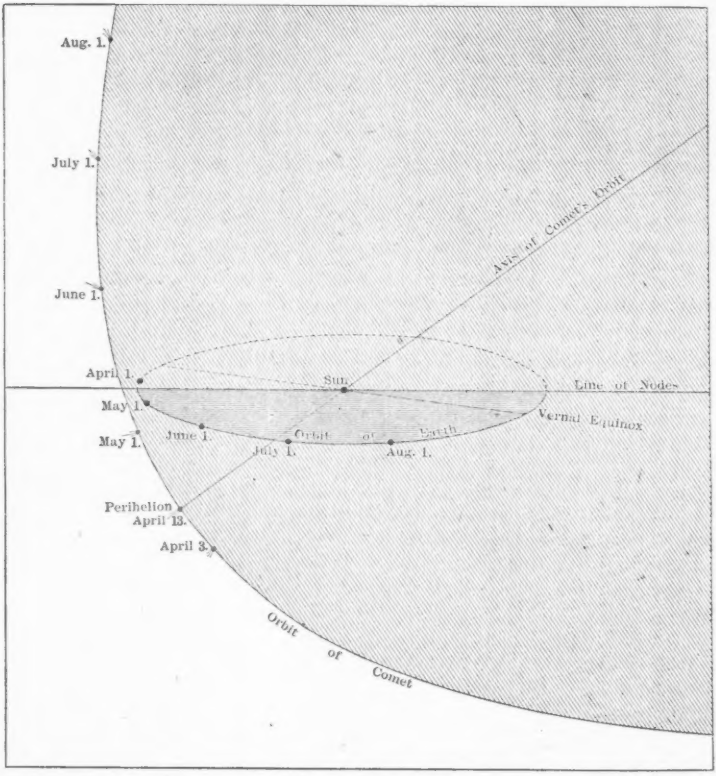
| | MAXIMA | | MAXIMA | | MINIMA |
|---|---|---|---|---|---|
| July 1 | X Capricorni | Aug. 7 | R Vulpeculæ | July 1 | T Capricorni |
| 2 | R Corvi | 7 | R Ceti | 1 | $L^2$ Puppis |
| 2 | R Boötis | 7 | Y Libræ | 5 | S Carini |
| 2 | R Persei | 8 | R Ursæ Majoris | 10 | R Centauri |
| 2 | R Geminorum | 8 | R Pegasi | 11 | R Scuti |
| 3 | U Cassiopeiæ | 9 | S Ursæ Majoris | 14 | R Arietis |
| 3 | S Scorpii | 10 | R Carini | 14 | U Monocerotis |
| 4 | R Aquarii | 11 | U Geminorum | 19 | R Cancri |
| 4 | U Boötis | 11 | R Virginis | 20 | R Lyræ |
| 6 | S Sagittarii | 13 | R Arietis | 25 | S Ceti |
| 10 | R Comæ | 13 | R Lacertæ | 26 | W Capricorni |
| 10 | R Sculptoris | 13 | U. Libræ | 30 | U Virginis |
| 18 | R Sagittarii | 14 | T Libræ | 30 | V Cygni |
| 24 | $R^2$ Libræ | 14 | S Ophiuchi | 31 | W Tauri |
| 26 | S Vulpeculæ | 15 | R Scuti | 31 | R Sagittæ |
| 27 | R Leonis Minoris | 15 | S Arietis | Aug. 2 | S Aquilæ |
| 27 | Y Virginis | 16 | S Cephei | 5 | X Boötis |
| 28 | Z Scorpii | 16 | R Sagittæ | 5 | S Canis Minoris |
| 29 | R Delphini | 17 | T Ursæ Majoris | 7 | S Delphini |
| 30 | R Scorpii | 17 | R Pegasi | 16 | T Herculis |
| 30 | V Ceti | 18 | U Ceti | 22 | R Leporis |
| Aug. 1 | U Monocerotis | 19 | V Tauri | 29 | U Monocerotis |
| 2 | W Cygni | 25 | T Cephei | | |
| 3 | S Herculis | 28 | S Cygni | | |
| 4 | R Lyræ | 29 | W Scorpii | | |
| 5 | Z Virginis | 30 | $L^2$ Puppis | | |
| 5 | T Hydræ | 30 | U Aquarii | | |
| | | 30 | V Ceti | | |

## COMET NOTES.

**Denning's Comet *a* 1894.**—Our last observation of this comet was obtained on the night of May 3. It was then exceedingly faint, and will probably not be visible, even in the largest telescopes, in June.

**Gale's Comet *b* 1894.**—This comet which we reported last month as too far south for observation in our latitude has come rapidly north and is now almost out of view from the place of discovery. The orbit is almost perpendicular to that of the Earth, so that it is probably not a periodic comet, and the parabolic elements last received appear to represent the observations fairly well. Mr. Ellery, Government Astronomer, at Melbourne, Australia, has telegraphed the following elements:

$$\left.\begin{array}{ll} T & = 1894 \text{ April } 13.75 \text{ Greenwich M. T.} \\ \omega & = 324^\circ\ 19' \\ \Omega & = 206\ \ 15 \\ i & = \ \ 87\ \ 15 \\ q & = 0.9849 \end{array}\right\} 1894.0$$




From these elements we have calculated the ephemeris, given in another place. During the next three months it will move northeast through Leo, Leo Minor and Ursa Major into Canes Venatici. It is growing rapidly fainter and will doubtless be invisible before it has completed the course indicated.

The accompanying cut shows the orbit of the comet in relation to that of the Earth. It will be seen that the comet was near perihelion when discovered, that

it was rapidly approaching the Earth, that it passed the point nearest to the latter about May 1, and that now it is rapidly receding.

The comet was first seen in northern latitudes by Mr. Douglass at Lowell Observatory, Flagstaff, Arizona, April 26. At Northfield cloudy weather prevented observations until May 3, when the comet was visible to the naked eye as a hazy star of the fifth magnitude. No tail was visible to the naked eye or with an opera glass, but with the 16-inch telescope the tail could be traced 20′ or 30′ from the nucleus. A photograph taken with our 6-inch Brashear camera on May 5 with an exposure of one hour shows very faint traces of a tail extending to the edge of the plate, a little over 6°. Unfortunately the 2½-inch camera happened to be provided with a poor plate and showed the merest trace of a tail in the same time.

Mr. Barnard at Lick Observatory was more fortunate and succeeded in getting a very beautiful picture of the comet with an exposure of two hours and twenty minutes on the night of May 3. He obtained a second successful photograph, on May 5.

This comet was observed by Mr. Douglass at the Lowell Observatory, Arizona, on April 26th, $15^h$ G. M. T., in R. A. $6^h\ 50^m$, and Decl. 33° 32′ south. He described it as of 5th magnitude brightness; circular, with a central nucleus, and a diameter approximately four minutes of arc, and a narrow tail eight minutes long. On April 28th he found it of the fourth magnitude, and from these and subsequent observations its positions showed it to be gaining somewhat on its ephemeris.

## Ephemeris of Gale's Comet, *b* 1894.

| Greenwich Midn. | R. A. | Decl. | log *r*. | log Δ | Br. |
|---|---|---|---|---|---|
| | h m | ° | | | |
| June 1 | 11 02.3 | + 38 39 | 0.1086 | 9.9869 | 0.48 |
| 3 | 07.9 | 39 21 | | | |
| 5 | 13.3 | 39 57 | | | |
| 7 | 18.4 | 40 28 | | | |
| 9 | 23.3 | 40 56 | 0.1366 | 0.0694 | 0.29 |
| 11 | 28.0 | 41 20 | | | |
| 13 | 32.5 | 41 41 | | | |
| 15 | 36.9 | 41 59 | | | |
| 17 | 41.1 | 42 14 | 0.1642 | 0.1369 | 0.19 |
| 19 | 45.3 | 42 27 | | | |
| 21 | 49.4 | 42 39 | | | |
| 23 | 53.4 | 42 49 | | | |
| 25 | 11 57.3 | 42 57 | 0.1912 | 0.1935 | 0.13 |
| 27 | 12 01.1 | 43 04 | | | |
| 29 | 04.8 | 10 | | | |
| July 1 | 08.5 | 15 | | | |
| 3 | 12.1 | 19 | 0.2172 | 0.2415 | 0.09 |
| 5 | 15.8 | 22 | | | |
| 7 | 19.4 | 24 | | | |
| 9 | 23.1 | 25 | | | |
| 11 | 26.7 | 25 | 0.2418 | 0.2825 | 0.07 |
| 13 | 30.3 | 24 | | | |
| 15 | 33.8 | 23 | | | |
| 17 | 37.3 | 22 | | | |
| 19 | 40.8 | 20 | 0.2684 | 0.3181 | 0.05 |
| 21 | 44.4 | 18 | | | |
| 23 | 47.9 | 16 | | | |
| 25 | 51.4 | 13 | | | |
| 27 | 54.9 | 10 | 0.2882 | 0.3497 | 0.04 |
| 29 | 12 58.4 | 06 | | | |
| 31 | 13 01.9 | + 43 02 | | | |

**Tempel's Periodic Comet.**—This comet was found very near the predicted place on the morning of May 9 by Mr. Finlay an astronomer at the Cape of Good Hope. The observed position of the comet was as follows:

May 8.6628 Gr. M. T.; R. A. $23^h\ 45^m\ 21^s.1$; Decl. $-4°\ 51'\ 18''$. This gives as the corrections to Mr. Schulhof's ephemeris $+47^s$ in R. A. and $-1'.9$ in Decl. remarkably small corrections considering the fact that the comet has not been observed since 1878. The comet is described as circular, less than 1′ in diameter, 11 magnitude or fainter, with some central condensation and no tail. It is now at its greatest theoretical brightness but in a quite unfavorable position for observation in the northern hemisphere, owing to the morning twilight in which it must be observed.

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**Ephemeris of Comet *a* 1894 (Denning).**—From Dr. Krueger's elements as given in A. N., Vol. 135, p. 135, I have computed the following ephemeris:

| Gr. M. T. | App. R. A. h m s | App. Decl. ° ′ | Log *r* | Log Δ |
|---|---|---|---|---|
| June 1.5 | 12 17 29 | + 5 20 | 0.3030 | 0.1514 |
| 3.5 | 20 23 | 4 49 | | |
| 5.5 | 23 16 | 4 18 | 0.3123 | 0.1744 |
| 7.5 | 26 7 | 3 48 | | |
| 9.5 | 28 57 | 3 19 | 0.3214 | 0.1966 |
| 11.5 | 31 46 | 2 50 | | |
| 13.5 | 34 35 | 2 21 | 0.3304 | 0.2183 |
| 15.5 | 37 22 | 1 53 | | |
| 17.5 | 40 8 | 1 26 | 0.3391 | 0.2393 |
| 19.5 | 42 54 | 0 59 | | |
| 21.5 | 45 40 | 0 33 | 0.3478 | 0.2552 |
| 23.5 | 48 25 | + 0 7 | | |
| 25.5 | 51 9 | − 0 19 | 0.3563 | 0.2791 |
| 27.5 | 53 53 | 0 44 | | |
| 29.5 | 12 56 36 | − 1 9 | 0.3647 | 0.2978 |

O. C. WENDELL.

Harvard College Observatory, May 15, 1894.

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**Gale's Comet** was picked up here on the evening of April 30, at half past eight 75 meridian time, in R. A. $7^h\ 43^m\ 20^s$; $-18°\ 40'$. I should have seen it two or three nights before this, only that my residence, about one hundred feet distant from the Observatory, cuts off my horizon in that direction. In all but two directions I am fortunate in having an excellent horizon. My own home, as mentioned, cuts off the horizon to the S. W.; and the residence of Mr. Wm. Smith, the founder of the Observatory, to a less extent, because at a greater distance to the S. E.

I found the comet surprisingly large, round and bright; all of which features appeared to increase from night to night as the comet attained a greater altitude. It was distinctly visible to the naked eye as a hazy star, even in the presence of a four-days-old Moon.

No tail was noticed in the telescope until the 9th of May, when a very narrow faint streak was detected pointed from the Sun. Visually in the telescope this could be traced about ¾ of a degree; but in a photograph taken the same evening, May 9th, the tail can be seen extending nearly three degrees from the head. The negative was made with a portrait camera of 3 inches aperture and 8 inches back focus; attached to the tube of the 10-inch equatorial, which latter was used as the guiding telescope, using a power of 450 diameters. The motion of the comet was followed, which was rapid in both right ascension and declination. An explanation of the high power used may prove of interest. The lower power eye-piece I had commonly used in guiding for stellar photographs had but one wire. As the comet was moving so rapidly in declination a double cross wire was necessary, but this there was not time to supply. I found, how-

XUM

ever, that by using a high power eye-piece with its small field, the comet could be kept central in that small field very easily without cross wires. The resultant photograph was very satisfactory in this respect. The plate used was a Cramer "Crown," and the exposure one hour and twenty minutes.

WILLIAM R. BROOKS.

Smith Observatory, Geneva, N. Y., May 17th, 1894.

**A Comet in the Corona of April 16, 1893.**—To day the Lick Observatory received positive copies (on glass) of the eclipse negatives taken by the English expeditions to Brazil and Africa. I can now announce that the object, to which particular attention was called in the October and April numbers of this journal,* is a comet.

On one of the negatives taken in Brazil identically the some form is shown as has already been described in the April number of ASTRONOMY AND ASTRO-PHYSICS except that the distance of the object from the Moon's outline is greater by ten minutes of arc. On two of the African plates the same object is very faintly shown at a still greater distance from the Moon's outline. The comet was apparently moving in the direction of the slender but conspicuous streamer (also shown on the English photographs) described in the April number of this journal. The following measures refer to a point on the sharply defined *inner* boundary of the tail which is nearest to the Moon's outline.

| Place. | Distance Moon's diameter = 1.00 | Remarks. |
|---|---|---|
| Mina Bronces, Chile. | 0.88 | Conspicuous and very certain. |
| Brazil. | 1.19 | " " " " |
| Africa. | 1.50 | Faint. |

Allowing for the difference of absolute time at the three stations the resulting geocentric daily motion is three and one-quarter degrees. The object was apparently diminishing in brightness quite rapidly, which indicates that its actual distance from the Sun was small and not simply due to projection. To remove if possible all doubt as to the position of the object on the African plates the original negatives should be specially examined. By giving a slight vibratory motion to the plate in its own plane very faint contrasts can be more readily detected. *There is not the slightest doubt with reference to the Chile and Brazil negatives.*

Lick Observatory, May 7, 1894. J. M. SCHAEBERLE.

**Elliptic Elements of Denning's Comet a 1894.**—In No. 317 of the *Astronomical Journal* Professor Boss gives the following elements which indicate that this comet belongs to the Jupiter family, having a period of less than 8 years:

Epoch: 1894 April 27.5 Greenwich M. T.

$$\left.\begin{array}{ll} M = & 9^\circ\ 31'\ 45''.28 \\ \omega = & 46\ \ 56\ \ 20\ \ .2 \\ \Omega = & 83\ \ 52\ \ 10\ \ .4 \\ i = & 5\ \ 34\ \ 33\ \ .3 \end{array}\right\} 1894.0$$

$$\varphi = 45\ \ 18\ \ 19\ \ .6$$

$$\mu = 446''.8386$$

$$\log a = 0.5999040;\ \text{period } 7.94 \text{ years.}$$

Mr. Schulhof gives similar elements in *Astronomische Nachrichten* No. 3227, making the eccentricity less, however, so that the period is only 6.74 years. He finds by Tisserand's criterion that the comet may be identical with that of Grischow (1743 I) or that of Blanpain (1819 IV). He gives the following comparison in which $n$ is the test quantity, $l$ is the longitude where the comet may approach nearest to Jupiter and the other letters represent the elements of the orbits:

| | $n$ | $\pi$ ° | $\Omega$ ° | $i$ ° | $e$ | $a$ | $l$ ° |
|---|---|---|---|---|---|---|---|
| Comet Grischow | 0.525 | 95 | 89 | 2 | 0.72 | 3.09 | 271 |
| Comet Blanpain | 0.517 | 69 | 79 | 9 | 0.71 | 3.11 | 248 |
| Comet Denning | 0.517 | 130 | 85 | 5 | 0.68 | 3.57 | 287 |

* 1893, page 732; 1894, page 307.

# NEWS AND NOTES.

Subscribers will please remember that the next number of this publication will be issued for August. None will appear in July.

In view of the very superior articles of this number we have given larger space than usual to ASTRO-PHYSICS, and although we have gone beyond our usual limits we have still been obliged to omit much useful minor matter.

Attention is called to the new full page advertisement of Messrs. T. Cooke & Sons, Buckingham Works, York, England. The exceedingly interesting facts that are suggested in it are more fully shown in excellent papers that have been recently prepared and published by H. D. Taylor on the perfectly achromatic astronomical objective. We are sorry that we had not space this time to give full and deserved notice of Mr. Taylor's optical studies. The same will appear later.

**Double Star Near H 3950**—The faint pair of stars, near H 3950, referred to by Mr. Sprague in the May number of *Astronomy and Astro-Physics*, (p 417) was first noted in the low-power sweeps at Madison) *Pub. Washburn* Observatory Vol. II), and subsequently measured by Comstock in his review of those stars (Vol. VI). It is much too wide in distance and too faint in magnitudes to be of any interest as a real double star. S. W. B.

**Professor Glassenapp's Double-Star Measures in 1892.**—The measures of double-stars made by Professor S. Glasenapp at Abastuman in 1892 have just appeared in a handsomely printed volume issued from the press of the Imperial Academy of Sciences of St. Petersburg. The observations include about six hundred pairs, principally from the Dorpat catalogue, each star being observed as a rule on two nights. The other pairs measured are from the OΣ and $\beta$ catalogues. The measures are excellent, and the stars judiciously selected considering the aperture of the equatorial.

It is to be regretted that this work could not have been continued, as the atmospheric conditions were found to be very favorable both as to the steadiness of the air, and the number of working nights. The elevation is some three hundred feet higher than Mt. Hamilton, and in point of latitude is much more favorably placed for observing south of the equator than any of the other Russian Observatories. From the amount of work done in the comparatively short time the Observatory was in active operation, it is evident that Professor Glasenapp made good use of his opportunities. Visitors to the Russian exhibit at the World's Fair will recall the beautiful photographs contributed by Professor Glasenapp of the picturesque Mountain Observatory at Abastuman. S. W. B.

**Eccentricity of the Orbit of the Companion to Algol.**—In the case of Algol, the total duration of phase, *i. e.*, the interval between the time when the light begins to diminish, and its complete restoration, must, at least approximately, correspond to the interval between first and last contact, speaking of the phase as a partial eclipse. This must be the time taken by the companion to describe an arc equal in length to the sum of its own diameter and Algol's. If the orbit is circu-

lar, this time will be the same for all parts; but if, as is more proabable, it is eccentric, the time will vary owing to the varying velocity; and if it is as eccentric as is usual in the case of binary stars, the times for different parts must vary very considerably. If, then, there is a secular variation of periastron, the different minima will correspond to different parts of the orbit, and there ought to be a variation in the duration of the phase.

But there is an observed variation in the intervals between the phases; and from this fact Chandler has proved that there is a third invisible member of the system, and has calculated its distance and mass. This third body must perturb the close companion, and in particular, must cause a rotation of periastron.

Knowing the mass and distance, the amount of this perturbation could be calculated on different assumptions as to the form of the orbit, and in this way the eccentricity deduced, if there have been any observed irregularities in the duration of the phase; if none have been noticed, it seems to me that it would be well to observe the duration, in the hope that at some future time the eccentricity could be computed.

Of course the variation of periastron may be so slow that no observable effect would be produced, except in a very long space of time, but it seems to me that it is not unlikely to be fairly rapid.

There are two other perturbations which would cause a change in the duration of phase, *viz.*: (1) an alteration in eccentricity, (2) variation of the plane of the orbit, causing the companion to travel along a chord of the disc of the primary, more or less remote from a diameter, than the one it traverses now; this would alter the magnitude of the phase as well as its duration.

Changes due to these latter causes would, however, be much slower, and in comparison insignificant. J. R. HOLT.

6 Harrington Street, Dublin.

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**Shape of the Discs of the Satellites of Jupiter.**—In Dr. Barnard's article on this subject in ASTRONOMY AND ASTRO-PHYSICS for April there is an assumption which will bear criticism. He considers that the ease of detecting any malformation is mainly a function of the aperture of the telescope, and consequently decides that the Arequipa observations on Jupiter's satellites must stand or fall by the verdict of the Lick instrument. Since the ellipticity of a disc does not vary with the aperture there can exist only the minor differences of size and brilliancy of image between the Arequipa and the Lick observations. The power used in Arequipa was 700 or more and the aperture 13 inches. Dr. Barnard used a power of 1,000 or more with an aperture of 36 inches. The discs he saw were therefore one and one-half times as large and their brilliancy nearly four times as great.

The most favorable conditions of light and size of image for detecting ellipticity must vary with the observer. According to my recollection of the appearance of the satellites at Arequipa, IV might have been brighter to advantage, while I, II, and III were bright enough to satisfy all the needs of observation; and it seems to me quite possible that much increase would have rendered their shape more difficult of observation through irradiation. In the matter of size of image the Lick telescope had the advantage, yet it was not very great. To express it roughly Dr. Barnard saw the discs about one-half of the apparent diameter of our Moon to the naked eye, and we saw them one-third of the same.

I desire also to call attention to the marked difference between individuals in their power of observing minute ellipticities. After I had for some time seen I elliptical, I observed II many times before acknowledging that it was not per-

manently round, thinking Professor W. H. Pickering mistaken in his observations on it. Yet after a time my eye seemed to acquire the power of seeing small errors in shape and our position-angles, taken independently, rarely exhibited unreasonable disagreement.

I conclude therefore that thus far no very great advantage lies with the great aperture of the Lick telescope, and that atmospheric conditions (having regard to the diameter of the lens, because a larger lens requires a more steady atmosphere) and individuality of the observer, enter largely into this question. As Professor Holden says, "everything is not yet settled with respect to Jupiter's satellite system."

A. E. DOUGLASS.

Lowell Observatory, Flagstaff, Arizona, May 6th, 1894.

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**Note Relative to $\beta$ 101, 9 Argus, $\alpha = 7^h\ 46^m$, $\delta = -13^\circ\ 35'$.**—In No. 116 of ASTRONOMY AND ASTRO-PHYSICS, Mr. Burnham has derived for this star an orbit which indicates extraordinarily rapid motion of the components during the past two years. This motion is confirmed by the following observations which I have made with the 40 cm. equatorial of the Washburn Observatory.

| | $p$ | $s$ | Power. | |
|---|---|---|---|---|
| | ° | ″ | | |
| 1894.230 | 292.5 | 0.45 est. | 792 | Blurred. |
| 246 | 284.8 | 0.35 | 792 | Blurred but separated. |
| 258 | 282 6 | 0.29 | 1540 | The quadrant is right. |
| 1894.24 | 286 6 | 0.36 | | |

The measured distance agrees well with the ephemeris given by Professor Glasenapp, *Monthly Notices*, March 1894, but the position-angle is eleven degrees greater than is given by the ephemeris.

GEORGE C. COMSTOCK.

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**Comet Medals.** In *English Mechanic* April 27, 1894 our excellent friend W. F. Denning, of England, appears to be guilty of scientific heresy. The charge is based on the following paragraph, page 220:

"I have written to Professor Holden of the Lick Observatory declining the Comet medal of the Astronomical Society of the Pacific. I quite fail to appreciate the utility of such awards. They afford no stimulus or encouragement to observation, and they are certainly no recompense for the labor involved in finding a comet. A man has his reward in the fact of success, and a bit of bronze is not likely to influence him in any way."

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**From Canada.** At the meeting of the Astronomical and Physical Society of Toronto on May 1, 1894, Mr. Thomas Lindsay read a paper on "Fallacies in Mathematics and Astronomy." Errors of the early ages regarding the form, magnitude and motion of the Earth were discussed, and reference was made to the difficulty of accounting for those gross mistakes. It was said that no one who is not altogether incapable of grasping the fundamental principles of geometry can fail to comprehend, in outline at least, the system of modern astronomy; yet the early philosophers, who gave the science of geometry to the world, seemed to have been ignorant of its application to things around them.

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**The Chicago Academy of Sciences.** *Section of Astronomy and Mathematics, May 14th.*—The regular monthly meeting was held at the Physical Laboratory

of Northwestern University, Evanston, Ill., Professor G. W. Hough, President, in the chair.

Professor Henry Crew read the first paper of the evening on "*The Concave Grating and its Relation to Spectroscopy, illustrated by Apparatus in the Laboratory.*" The speaker, in introducing his subject, sketched the work of Fraunhofer on Spectra, and discussed the early work of Rutherford and others in constructing gratings for spectroscopic purposes. He developed the principal formulæ employed in the theory of the grating, and showed how the whole theory of the spectroscope followed from one formula. He then spoke of the invention of the concave grating by Professor Rowland, who had also perfected his discovery both theoretically and practically. Dr. Crew explained by diagrams the construction and use of the apparatus, and pointed out its particular advantages, especially in securing a normal spectrum. After explaining the mathematical theory of the apparatus, the speaker invited the members of the Academy to the Laboratory, where he exhibited the practical working of a fine concave grating.

The second paper of the evening was read by Professor Malcolm McNeill on "*The Life and Works of Kepler.*" The speaker gave an interesting account of Kepler's youth, his education, and his early religious dissent, which influenced his whole career and caused him to be continually persecuted, although ever since leaving the University of Tubingen he had desired an official position in the church. Professor McNeill then gave an account of Kepler's relations with Tycho, and alluded to the great difficulties he afterwards encountered in securing the use of Tycho's manuscripts from his heirs. He then sketched the career of Kepler in discovering the laws of planetary motion, and pointed out the difficulties which were continually encountered and finally overcome.

The speaker called attention to the importance of Kepler's discovery that the planes of the orbits of the planets pass through the Sun, and remarked that the order of Kepler's laws as ordinarily given is not historically correct, the law of equal areas being the first discovered. He said that Kepler had worked twenty-two years on the harmonic law, the squares of the times of revolution are as the cubes of the major axes, and that he had regarded this as his principal discovery. Kepler's manuscripts had been preserved, and finally secured by the Empress Catherine of Russia, so that they are now preserved in the Observatory of Pulkowa. The Opera Omnia edited by Fritche gives the most authoritative information regarding Kepler and his splendid discoveries, which laid the foundation for Newton. Professor McNeill was of the opinion that while Kepler had the true spirit of a discoverer, he had also the character of a mystic, and that these two traits appear clearly in his writings.

After some discussion, the section withdrew to the Dearborn Observatory, where the 18-inch telescope was placed at the disposal of the members. *σ.*

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The subscription price to ASTRONOMY AND ASTRO-PHYSICS in the United States and Canada is $4.00 per year in advance. For foreign countries it is £1 or 20.50 marks per year, in advance. Recent increase in price to foreign subscribers is due to increase of postage because of enlarged size during the year 1892. Messrs. Wesley & Son, 28 Essex Street, Strand, London, are authorized to receive subscriptions. Payment should be made in postal notes or orders or bank drafts, Currency should *always* be sent by registered letter.

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All communications pertaining to Astro-Physics or kindred branches of physics should be sent to George E. Hale, Kenwood Observatory, of the University of Chicago, Chicago, Ill.

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